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(54) Device for non-invasive determination of glucose concentration in blood

(57) A device for the non-invasive determination of glucose concentration in the blood of a subject comprises a light source for producing near-infrared radiation having successive wavelengths within the range of 1300 to 2500 nm, a light projecting unit for projecting the near-infrared radiation on the skin of the subject, a light receiving unit for receiving resulting radiation emitted from inside the skin, and a unit for analysing the spectrum of the resulting radiation and determining the glucose concentration according to the spectrum analysis. The light receiving unit is separated from the light projecting unit by a distance within the range of 0.1 to 2 mm to selectively sense the resulting radiation emitted from a dermis layer positioned under the epidermis layer of the skin. The glucose concentration in the blood is determined by the spectrum analysing unit by using the spectrum analysis and a statistically-obtained correlation between the glucose concentration in the dermis region and that in the blood.

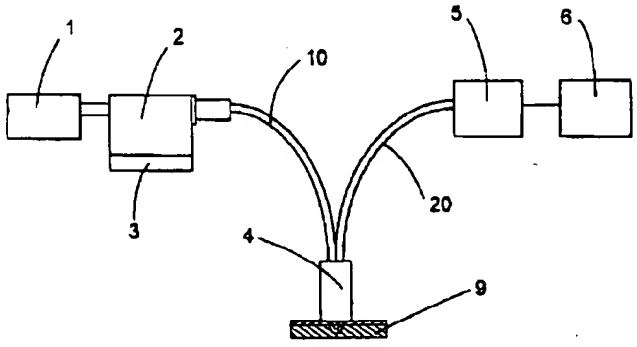

FIG. 1

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Description

TECHNICAL FIELD

The present invention relates to a device for non-invasive determination of a glucose concentration in the blood of a subject with improved accuracy.

BACKGROUND ART

In the past, a near-infrared spectroscopic analysis has been known as a method comprising the steps of projecting near-infrared radiation having wavelengths of 800 nm to 2500 nm to a target, receiving a resulting radiation, i.e., a transmission light or reflection light from the target, and performing a spectrum analysis of the resulting radiation. This method has the following advantages:

(1) Since a low energy electromagnetic wave is used, it is possible to avoid the occurrence of radiation damage of the target.
(2) An absorption by water of near-infrared radiation is smaller than that of infrared radiation, therefore, it is possible to select an aqueous solution as the target.
(3) It is possible to perform the spectroscopic analysis under various physical states of the target, i.e., a solid state such as powder or fiber, a liquid state and a gas state.

As an application of the near-infrared spectroscopic analysis, it is increasingly utilized for non-invasive determination of a glucose concentration in the body of a subject. For example, U.S. Patent No. 5,379,764 discloses a method of determining a glucose concentration in the blood of a patient. FIG. 39 is a schematic diagram of a device for practicing the method. Near-infrared radiation is provided from a light source **1Y** which is capable of producing the radiation over the range of 700 nm to 3000 nm, and projected on a skin **9Y** of the patient through a first lens system **2Y** and an input radiation conductor **10Y**, e.g., optical fibers. A resulting back-scattered radiation emitted from the inside of the skin **9Y** is received by a sensing radiation conductor **20Y**. The received radiation is provided through a second lens system **3Y** to a spectrum analyzer/detector **30Y**, and then a data processor **40Y** to make a spectrum analysis of the received radiation and determine the glucose concentration in the blood of the patient by using a multivariate analysis. The obtained glucose concentration is sent to a display monitor **50Y** and an output recorder **60Y**.

On the other hand, PCT Publication No. WO94/10901 discloses a method for determining a glucose concentration in a biological matrix. As shown in FIG. 40, the method uses a light emitter (not shown) for projecting a primary light **1Z** of near-infrared radiation at a projection site **10Z** to a skin **9Z** of the biological matrix, and first and second light receivers (not shown) for sensing resulting secondary lights (**2Z**, **3Z**) emitted from the skin **9Z** at first and second detection sites (**20Z**, **30Z**). The first detection site **20Z** is spaced from the projection site **10Z** by a distance **D1** of at least 0.5 mm, and preferably 1 mm. The second detection site **30Z** is spaced from the projection site **10Z** by a distance **D2** (≠**D1**) of 30 mm or less. A light path passing through the skin **9Z** between the projection site **10Z** and the first detection site **20Z** is different from the light path passing through the skin between the projection site and the second detection site **30Z**. Therefore, the glucose concentration can be derived from the dependence of the intensity of the secondary light from the relative position of the projection site and the detection site.

By the way, each of these measurements of the glucose concentration is performed by projecting near-infrared radiation on a skin of a forearm or finger of the subject. The skin is generally composed of three layers, that is, an epidermis layer having a thickness of about 100 μm, a dermis layer having a thickness of about 1 mm and positioned under the epidermis layer, and a subcutaneous-tissue layer including adipose cells and positioned under the dermis layer. These layers shows different glucose concentrations. Therefore, if variations in glucose concentration on such a complex skin structure is carefully analyzed, it will be possible to determine the glucose concentration in the blood with improved accuracy.

Thus, there is room for further improvement on the measurements of the glucose concentration of the prior art.

The present invention is directed to a device for non-invasive determination of a glucose concentration in the blood of a subject with improved accuracy. The device comprises a light source for producing near-infrared radiation having successive wavelengths within a range of 1300 nm to 2500 nm, a light projecting unit for projecting the near-infrared radiation on a skin of the subject, light receiving unit for receiving a resulting radiation emitted from the inside of the skin, and a spectrum analyzing unit for making a spectrum analysis of the resulting radiation and determining the glucose concentration in the blood according to the spectrum analysis. The device of the present invention is characterized in that the light receiving unit is separated from the light projecting unit by a distance defined within a range of 0.1 mm to 2 mm to selectively receive the resulting radiation emitted from a dermis layer positioned under an epidermis layer of the skin. The glucose concentration in the blood of the subject is determined in the spectrum analyzing unit by using the spectrum analysis and a statistically-obtained correlation between glucose concentration in dermis layer and glucose concentration in blood of test subjects. Due to a relatively uniform glucose concentration in the dermis layer, it is possible to reliably provide the glucose concentration in the blood

of the subject with improved accuracy.

It is preferred that the light projecting unit is formed with a plurality of first optical fibers each of which is connected at its one end to the light source, and provides the near-infrared radiation from its opposite projection end, and that the light receiving unit is formed with a plurality of second optical fibers each of which is connected at its one end to the spectrum analyzing unit, and receives the resulting radiation at its opposite receiving end. In particular, it is preferred that the first optical fibers make a bundle in cooperation with the second optical fibers, and projection ends of the first optical fibers and receiving ends of the second optical fibers are exposed at an end surface of the bundle in such a pattern that a center of each of the projection ends is separated from a center of an adjacent receiving end by a distance defined within the range of 0.1 mm to 2 mm, and more preferably 0.2 mm to 1 mm.

In a preferred embodiment of the present invention, the center of each of the projection ends is at least spaced from the center of the adjacent receiving end by a distance L expressed by the following equation;

$$L = \{\sqrt{2} \times (d1 + d2)\}/2$$

wherein d1 is a diameter of the first optical fiber, and d2 is a diameter of the second optical fiber. When the first and second optical fibers have a same diameter d, the distance L is expressed by the equation;

$$L = \sqrt{2} \times d.$$

In a further preferred embodiment of the present invention, the bundle is formed with a plurality of sub-bundles, in each of which a projection end of the first optical fiber is disposed on the end surface of the bundle at a center of a hexagonal pattern, and six receiving ends of the second optical fibers are disposed at corners of the hexagonal pattern. In this case, it is preferred that at least one of the receiving ends of each of the sub-bundles is common with an adjacent sub-bundle. This provides an advantage of uniformly detecting the resulting radiation selectively including spectrum information of the dermis layer from a relatively wide area of the skin. Therefore, the reliability of measurement of the glucose concentration could be improved.

In another preferred embodiment of the present invention, the device comprises a supplemental light receiving unit which is formed with plurality of third optical fibers. Each of the third optical fibers is connected at its one end to the spectrum analyzing unit, and selectively receives at its opposite receiving end the resulting radiation emitted from the epidermis layer. The receiving end of each of the third optical fibers is disposed on the end surface of the bundle between the projection end and one of the receiving ends in the respective hexagonal pattern. As explained before, the resulting radiation received by the second optical fibers selectively contains the spectrum information of the dermis layer, however, a small amount of spectrum information of the epidermis layer is inevitably included in the resulting radiation. The supplemental light receiving unit is preferably used to subtract the spectrum information of the epidermis layer from the resulting radiation received by the second optical fibers. As a result, it is possible to achieve the spectrum analysis of the resulting radiation, while minimizing the influence of undesirable spectrum information from the epidermis layer.

These and still other objects and advantages will become apparent from the following description of the preferred embodiments of the invention when taken in conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a device for non-invasive determination of a glucose concentration in the blood of a subject of a first embodiment of the present invention;

FIG. 2 is an end view of an optical fiber bundle of the first embodiment;

FIG. 3 is a partially enlarged view of FIG. 2;

FIG 4 is a schematically cross-sectional view of a light path passing through a skin between a projection end and an adjacent receiving end;

FIG. 5 is an end view of an optical fiber bundle of a first modification of the first embodiment;

In FIGS. 6A to 6C, FIG. 6A is an end view of an optical fiber bundle of a second modification of the first embodiment, and FIGS. 6A and 6B show a method of forming the optical fiber bundle;

FIG. 7 is a perspective view of an optical fiber bundle of the second modification;

FIG. 8 is an end view of an optical fiber bundle of a second embodiment;

FIG. 9 is a spectrum diagram showing results of an experiment explained in the second embodiment;

FIG. 10 is an end view of an optical fiber bundle of a first modification of the second embodiment;

FIG. 11 is a schematic diagram of a device for non-invasive determination of a glucose concentration in the blood of a subject of a third embodiment of the present invention;

FIG. 12 is an end view of an optical fiber bundle of the third embodiment;

FIG. 13 is a schematic diagram of a device for non-invasive determination of a glucose concentration in the blood of a subject of a fourth embodiment of the present invention;

FIG. 14 is an end view of an optical fiber bundle of the fourth embodiment;

FIG. 15 is a schematically cross-sectional view showing three different light paths directing from a projection end to receiving ends through a skin;

FIG. 16 is an end view of an optical fiber bundle of a first modification of the fourth embodiment;

FIG. 17 is an end view of an optical fiber bundle of a second modification of the fourth embodiment;
FIG. 18 is an end view of an optical fiber bundle of a fifth embodiment;
FIG. 19 is a cross-sectional view of a supporting member for supporting optical fibers used in the fifth embodiment;
FIG. 20 shows a method of forming the optical fiber bundle of the fifth embodiment;
FIG. 21 is an end view of an optical fiber bundle of a first modification of the fifth embodiment;
FIG. 22 is an end view of an optical fiber bundle of a second modification of the fifth embodiment;
FIG. 23 is an end view of an optical fiber bundle of a sixth embodiment;
FIG. 24 shows a method of forming the optical fiber bundle of the sixth embodiment;
FIG. 25 is an end view of an optical fiber bundle of a first modification of the sixth embodiment;
FIG. 26 is a perspective view of a supporting member for supporting optical fibers used in the first modification of the sixth embodiment;
FIG. 27 shows a method of forming the optical fiber bundle of the first modification of the sixth embodiment;
FIG. 28 is an end view of an optical fiber bundle of a second modification of the sixth embodiment;
FIG. 29 is an end view of a optical fiber bundle of a seventh embodiment;
FIG. 30 is a perspective view of a spacer sheet mounting thereon first and second optical fibers;
FIG. 31 is an end view of an optical fiber bundle of a first embodiment of the seventh embodiment;
FIG. 32 shows a method of forming the optical fiber bundle of the first modification of the seventh embodiment;
FIG. 33 is a schematic diagram of a device for non-invasive determination of a glucose concentration in the blood of a subject of an eighth embodiment of the present invention;
FIG. 34 is an end view of an optical fiber bundle of the eighth embodiment;
FIG. 35 is an end view of an optical fiber bundle of a ninth embodiment;
FIG. 36 is an end view of an optical fiber bundle of a tenth embodiment;
FIG. 37 is a schematic diagram of a device for non-invasive determination of a glucose concentration in the blood of a subject of an eleventh embodiment of the present invention;
FIG. 38 is an end view of an optical fiber bundle of the eleventh embodiment;
FIG. 39 is a schematic diagram of a device for non-invasive determination of a glucose concentration in the blood of a patient of the prior art; and
FIG. 40 is a schematic diagram illustrating a method for determining a glucose concentration in a biological matrix of the prior art.

DETAIL DESCRIPTION OF THE PREFERRED EMBODIMENTS

(First Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of the present invention is shown in FIG. 1. The device is formed with a light source unit comprising a halogen lamp **1** of about 150 W, a diffraction grating unit **2** as a spectroscope of alight provided from the halogen lamp, and a stepping motor unit **3** for controlling a rotation angle of the diffraction grating to provide near-infrared radiation, an optical fiber bundle **4** having a plurality of first optical fibers **10** for projecting the near-infrared radiation on a skin **9** of the subject and a plurality of second optical fibers **20** for receiving the resulting radiation emitted from the skin, a light receiving unit **5** connected to the second optical fibers, and a spectrum analyzing unit **6** for making a spectrum analysis of the resulting radiation and determining the glucose concentration in the blood of the subject according to the spectrum analysis.

Each of the first optical fibers **10** is connected at its one end to the light source unit, and provides the near-infrared radiation from its opposite projection end. Each of the second optical fibers **20** is connected at its one end to the light receiving unit **5**, and receives the resulting radiation at its opposite receiving end. The optical fiber bundle **4** has an end surface at which the bundle is pressed against the skin. It is preferred to use a pressure gauge and a fixture for pressing the optical fiber bundle **4** against the skin by a required pressure. The projection ends of the first optical fibers **10** and the receiving ends of the second optical fibers **20** are exposed on the end surface of the optical fiber bundle **4**. As shown in FIG. 2, the optical fiber bundle **4** is formed with a plurality of sub-bundles, in each of which a projection end of the first optical fiber **10** is disposed on the end surface of the bundle at a center of a hexagonal pattern, as shown by a dotted line in FIG. 2, and six receiving ends of the second optical fibers **20** are disposed at corners of the hexagonal pattern. A receiving end **20a** of each of the sub-bundles is common with an adjacent sub-bundle in an X-axis direction. Two receiving ends **20b** of each of the sub-bundles are common with an adjacent sub-bundle in a Y-axis direction.

In each of the sub-bundles, a distance L between a center of the projection end of the first optical fiber **10** and a center of an adjacent receiving end of the second optical fiber **20** is determined within a range of 0.1 mm to 2 mm, and more preferably a range of 0.2 mm to 1 mm, to selectively receive the resulting radiation emitted from a dermis layer of the skin **9**. When the distance **L** is less than 0.1 mm, the resulting radiation contains a large amount of spectrum information of an epidermis layer of the skin **9**. On the other hand, as the distance **L** is more than 2 mm, spectrum information of a subcuta-

neous tissue layer positioned under the dermis layer increases. Variations in glucose concentration of the dermis layer is smaller than those of the epidermis layer and the subcutaneous tissue layer. The present device is directed to selectively extract spectrum information of the dermis layer and determine the glucose concentration in the blood of the subject according to the spectrum information. In this embodiment, the first and second optical fibers (**10**, **20**) have a same diameter **d** of 200 μm, and the distance **L** is 500 μm. In the present invention, it is preferred to use first and second optical fibers each having a diameter within a range of 70 μm and 1000 μm.

By the way, when the receiving ends of the second optical fibers **20** are disposed, as shown in FIG. 2, there are a lot of combinations as to the distance between the projection end and the receiving end. For example, as shown in FIG. 3, a distance **L1** between a projection end of a hexagonal pattern and a receiving end of an adjacent hexagonal pattern is about two times of the distance L. In addition, a distance **L2** between a projection end of a hexagonal pattern and a receiving end of a further-spaced hexagonal pattern is about three times of the distance L. A light path formed through the skin **9** between a projection end and a receiving end separated therefrom by the distance **L** is schematically shown in FIG. 4. In an optically-opaque, complex skin structure, it would be difficult to precisely discuss about light-transmission and light-scattering phenomena according to Lambert-Beer's law. However, as a total length of the light path increases, a light amount to be received is rapidly decreased. For example, when a light path is twice as long as the light path formed between the distance L, the light amount would be decreased to 1/10 or less. When a light path is three times as long as the light path formed between the distance L, the light amount would be decreased to 1/100 or less. Therefore, the light amount received by each of the receiving ends would be substantially equal to a total of light amount provided by light paths formed between the receiving end and adjacent projection ends separated therefrom by the distance L. In the present invention, since the distance **L** is determined such that each of the light paths is mostly formed in the dermis layer **91**, as shown in FIG. 4, it is possible to selectively detect the spectrum information of the dermis layer.

The light receiving unit **5** comprises a photo-diode made of In-Ga-As and having a wavelength-sensitivity of 0.9 μm to 1.7 μm, amplifier and an A/D converter. Alternatively, a conventional light receiving unit can be used. The spectrum analyzing unit **6** comprises a microcomputer, in which a multivariate analysis is performed by the use of adsorption spectrum of near-infrared radiation of 1.25 μm to 1.7 μm. A calibration line (or calibration equation) obtained by a PLS (Partial Least Square) regression analysis is used to the multivariate analysis. For example, the calibration line can be obtained by the PLS regression analysis using two variables. One of the variables is data of the adsorption spectrum which are obtained from test subjects, and the other one is data of the glucose concentration in dermis layer which are measured from the test subjects by an invasive method. Thus, a first statistically-obtained correlation between the adsorption spectrum and the glucose concentration in dermis layer and a second statistically-obtained correlation between the glucose concentration in dermis layer and the glucose concentration in blood are used in the spectrum analyzing unit **6**.

The light source unit provides near-infrared radiation having successive wavelengths within a range of 1300 nm to 2500 nm. When the wavelength is less than 1300 nm, it is difficult to obtain the resulting radiation having a good S/N ratio. Near-infrared radiation having wavelengths less than 1300 nm shows excellent transmittance in a living body. In other words, an absorption of the near-infrared radiation in the living body is very small. Therefore, when a projection end of the first optical fiber **10** is spaced from an adjacent receiving end of the second optical fiber **20** by the distance L within the range of 0.1 mm to 2 mm, it would be difficult to obtain the resulting radiation including a sufficient amount of spectrum information of the dermis layer by the use of near-infrared radiation having wavelengths less than 1300 nm. In particular, it is preferred use the near-infrared radiation having at least one of successive wavelengths from 1400 nm to 1800 nm, and successive wavelengths from 2000 nm to 2500 nm.

As a first modification of the first embodiment, it is possible to use an optical fiber bundle **4A** having a plurality of sub-bundles, as shown in FIG. 5. In each of the sub-bundles, a projection end of a first optical fiber **10A** is disposed at a center of a hexagonal pattern, and six receiving ends of second optical fibers **20A** are disposed at corners of the hexagonal pattern. This modification differs from the first embodiment in that each of the sub-bundles is independent from an adjacent sub-bundle without having a common receiving end. A distance **L** between the projection end and an adjacent receiving end is adequately determined to fall within the range of 0.1 mm to 2 mm.

As a second modification of the first embodiment, it is possible to use an optical fiber bundle **4B**, as shown in FIG. 6A. That is, the optical fiber bundle **4B** is formed with a single projection end of a first optical fiber **10B** disposed at a center of a hexagonal pattern and six receiving ends of second optical fibers **20B** disposed at corners of the hexagonal pattern. For example, the optical fiber bundle **4B** can be formed by preparing a circular plate **40B** having a plurality of through holes 41B arranged in the hexagonal pattern, as shown in FIG. 6B, and inserting the first ad second optical fibers (**10B**, **20B**) into the through holes, as shown in FIG. 6C. It is preferred that the projection and receiving ends of the first and second optical fibers (**10B**, **20B**) are slightly projected from an end surface of the optical fiber bundle **4B**, as shown in FIG. 7, to achieve a complete contact

between the skin and the projection and receiving ends. In this modification, each of the first and second optical fibers (**10B**, **20B**) has a diameter of 200 μm. A distance **L** between the projection end and the adjacent receiving end is adequately determined to fall within the range of 0.1 mm to 2 mm.

(Second Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of a second embodiment of the present invention is identical to that of the first embodiment except for a different pattern of sub-bundles of an optical fiber bundle **4C**. That is, as shown in FIG. 8, two receiving ends of second optical fibers **20C** of each of the sub-bundles are common with an adjacent sub-bundle. In this embodiment, each of first and second optical fibers (**10C**, **20C**) has a diameter of 200 μm. In each of the sub-bundles, a distance **L** between a center of a projection end of the first optical fiber **10C** and a center of an adjacent receiving end of the second optical fiber **20C** is 650 μm.

To show an advantage of the optical fiber bundle **4C**, an experiment was performed by the use of a phantom which is composed of an imitational epidermis layer having a thickness of about 50 μm as a top layer, an imitational dermis layer having a thickness of about 1 mm as an intermediate layer, and a lard layer having a thickness of about 1 cm as a bottom layer. The imitational epidermis and dermis layers are formed to have substantially same optical properties as the epidermis and dermis layers of the human skin. The lard layer is used as an imitational subcutaneous-tissue layer. In FIG. 9, an adsorption spectrum **S1** was measured by vertically pressing the optical fiber bundle **4C** against the top surface of the phantom. A comparative experiment was performed by the use of an optical fiber bundle which is substantially a same as the optical fiber bundle of FIG. 8 except that a distance between centers of a projection end and an adjacent receiving end is 6000 μm. In FIG. 9, an adsorption spectrum **S2** was measured by vertically pressing the comparative bundle against the top surface of the phantom. FIG. 9 also shows an adsorption spectrum **S3** of the lard layer. The spectrum **S3** of the lard layer has a large, relatively-sharp peak at the vicinity of 1730 nm, and a small, relatively-broad peak at the vicinity of 1420 nm. The spectrum **S2** is influenced by these two peaks of the lard layer. On the other hand, the influence of the two peaks to the spectrum **S1** is much smaller than the former case. From these considerations, it is suggested that the optical fiber bundle **4C** of the present invention can selectively provide an absorption spectrum of the dermis layer, while minimizing the influence of undesirable spectrum information from the subcutaneous tissue layer.

As a first modification of the second embodiment, it is possible to use an optical fiber bundle **4D**, as shown in FIG. 10. The optical fiber bundle **4D** is formed with a plurality of sub-bundles, in each of which a projection end of a first optical fiber **10D** is disposed at a center of a hexagonal pattern and six receiving ends of second optical fibers **20D** are disposed at corners of the hexagonal pattern Two receiving ends of each of the sub-bundles is common with an adjacent sub-bundle. Each of the first and second optical fibers (**10D**, **20D**) has a diameter **d** of 250 μm, and is covered by a nylon tube having an outer diameter **D** of 500 μm. Therefore, a distance **L** between centers of a projection end and an adjacent receiving end is 500 μm. A ratio of the number of the first optical fibers **10D** to the number of the second optical fibers **20D** is about 1 : 2.

(Third Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of a third embodiment of the present invention is identical to that of the first embodiment except for the following features. Therefore, no duplicate explanation to common parts and operation is deemed necessary. As shown in FIG. 11, an optical fiber bundle **4E** comprises a plurality of third optical fibers **30E** for selectively receiving a resulting radiation emitted from an epidermis layer of a skin of the subject. A diameter of the third optical fibers is 100 μm. Each of the third optical fibers **30E** is connected at its one end to a light receiving unit **5E**. In each of hexagonal patterns of subbundles of the optical fiber bundle **4E**, as shown in FIG. 12, a receiving end of the third optical fiber **30E** is disposed between a projection end of a first optical fiber **10E** and one of receiving ends of second optical fibers **20E**. A distance **L** between the projection end and the receiving end of the second optical fiber **20E** is adequately determined to fall within the range of 0.1 mm to 2 mm. A distance **L1** between the projection end and an adjacent receiving end of the third optical fiber **30E** is determined to be lower than the distance **L**. In the present invention, the resulting radiation received by the second optical fibers **20E** selectively contains the spectrum information of a dermis layer of the skin, however, a small amount of spectrum information of the epidermis layer is inevitably included in the resulting radiation. The third optical fibers **30E** are preferably used to subtract the spectrum information of the epidermis layer from the resulting radiation received by the second optical fibers **20E**. As a result, it is possible to achieve an accurate spectrum analysis of the resulting radiation, while minimizing the influence of the spectrum information of the epidermis layer.

(Fourth Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of a fourth embodiment of the present invention is identical to that of the first embodiment except for the following features. Therefore, no duplicate explanation to common parts

and operation is deemed necessary. As shown in FIGS. 13 and 14, an optical fiber bundle **4F** is formed with a plurality of sub-bundles, each of which is composed of a first optical fiber **10F** having a diameter of 500 μm, two second optical fibers (**20F, 21F**) having diameters of 500 μm and 250 μm, and a third optical fiber **30F** having a diameter of 100 μm. In each of the sub-bundles, a projection end of the first optical fiber **10F** is disposed on an end surface of the optical fiber bundle **4F** at an eccentric point of a circular pattern, and two receiving ends of the second optical fibers (**20F, 21F**) are disposed adjacent to the projection end in the circular pattern. The third optical fibers **30F** are connected to a light receiving unit **5F**. A receiving end of each of the third optical fibers **30F** is disposed on the end surface of the optical fiber bundle **4F** in the circular pattern so as to be closer to the projection end than the receiving ends of the second optical fibers (**20F, 21F**).

As shown in FIG. 15A, a distance **L** between a projection end and a receiving end of the second optical fiber **20F** of 500 μm is determined to fall within the range of 0.1 mm to 2 mm such that the receiving end can selectively sense the resulting radiation emitted from a center portion of a dermis layer **91F** of a skin **9F**. A distance **L1** between the projection end and a receiving end of the second optical fiber **21F** of 250 μm is determined such that the receiving end can selectively sense the resulting radiation emitted from an upper portion of the dermis layer **91F** adjacent to an interface between the dermis layer and an epidermis layer **90F** of the skin **9F**. The distance **L1** is determined to fall within the range of 0.1 mm to 2 mm and be smaller than the distance **L**. A distance **L2** between the projection end and a receiving end of the third optical fiber **30F** is determined such that the receiving end can selectively sense the resulting radiation emitted from the epidermis layer **90F**. The distance **L2** is smaller than the distance **L1**. As a result, it is possible to perform the spectrum analysis according to an adsorption spectrum of only the dermis layer **91E** by the use of subtractions of adsorption spectra obtained through the second and third optical fibers (**20F, 21F, 30F**). If necessary, the diameters of the first to third optical fibers (**10F, 20F, 21F, 30F**) will be adequately changed.

As a first modification of the fourth embodiment, it is possible to use an optical fiber bundle **4G** having a plurality of sub-bundles, as shown in FIG. 16. In this modification, the number of the sub-bundles is seven. Each of the sub-bundles is composed of a first optical fiber **10G** having a diameter of 500 μm, and three of second optical fibers (**20G, 21G**). One of the second optical fibers **20G** is of a diameter of 500 μm, and the rest of the second optical fibers **21G** are of a diameter of 250 μm. A distance **L** between a projection end and a receiving end of the second optical fiber **20G** of 500 μm, and a distance **L1** between the projection end and a receiving end of the second optical fibers **21G** of 250 μm, are adequately determined to fall within the range of 0.1 mm to 2 mm such that the distance **L** is larger than the distance **L1**.

As a second modification of the fourth embodiment, it is possible to use an optical fiber bundle **4H**, as shown in FIG. 17. The optical fiber bundle **4H** is composed of a first optical fiber **10H**, a second optical fiber **20H** having a same diameter as the first optical fiber, and a third optical fiber **30H** having a smaller diameter than the first optical fiber. In FIG. 17, a distance **L** between a projection end of the first optical fiber **10H** and a receiving end of the second optical fiber **20H** is determined to fall within the range of 0.1 mm to 2 mm such that the receiving end can selectively sense the resulting radiation emitted from the dermis layer. On the other hand, a distance **L1** between the projection end and a receiving end of the third optical fiber **30H** is determined to be smaller than the distance **L** such that the receiving end can selectively sense the resulting radiation emitted from the epidermis layer.

(Fifth Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of a fifth embodiment of the present invention is identical to that of the first embodiment except for the following features. As shown in FIG. 18, an optical fiber bundle **4J** is formed with a plurality of sub-bundles, in each of which a projection end of a first optical fiber **10J** is disposed at a center of a rectangular pattern and four receiving ends of second optical fibers **20J** are disposed at corners of the rectangular pattern. The sub-bundles are arranged on an end surface of the optical fiber bundle **4J** such that two receiving ends of each of the sub-bundles is common with an adjacent sub-bundle.

In each of the sub-bundles, it is preferred that a center of a projection end of the first optical fiber **10J** is at least separated from a center of an adjacent receiving end of the second optical fiber **20J** by a distance **L** which is expressed by the following equation;

$$L = \{\sqrt{2} \times (d1 + d2)\}/2$$

wherein **d1** is a diameter of the first optical fiber **10J**, and **d2** is a diameter of the second optical fiber **20J**. In this embodiment, each of the first and second optical fibers (**10J, 20J**) has a diameter **d** of 200 μm. Therefore, the distance **L** is determined to be more than 280 μm, as calculated by the following equation;

$$L = \sqrt{2} \times d.$$

To make this optical fiber bundle **4J**, a plurality of supporting members **40J** for supporting the first and second optical fibers (**10J, 20J**) are used. Each of the supporting members **40J** is formed with a coupling portion **41J**, a plurality of convex portions **42J**, and grooves **43J** formed between adjacent convex portions **42J**, as

shown in FIG. 19. The first and second optical fibers (10J, 20J) are disposed in the grooves 43J of the supporting members 40J. In this embodiment, a half of the supporting members 40J are used for the first optical fibers 10J, and the rest of the supporting members are used for the second optical fibers 20J.

A method of forming the optical fiber bundle 4J comprises the steps of alternately stacking up the supporting members 40J mounting thereon the first optical fibers 10J and the supporting members mounting thereon the second optical fibers 20J, as shown in FIG. 20, bonding the supporting members each other, and cutting off the coupling portions of the supporting members along a dotted line of FIG. 19 to expose the projection ends and the receiving ends on the end surface of the optical fiber bundle 4J.

As a first modification of the fifth embodiment, an optical fiber bundle 4K having first and second optical fibers (10K, 20K) arranged, as shown in FIG. 21, can be formed by the following method. Firstly, twenty five of the first optical fibers 10K each having a diameter of 200 μm, twenty five of the second optical fibers 20K each having a diameter of 200 μm, and fifty spacers 40K are prepared. Five first optical fibers 10K and five spacers 40K are alternately aligned, and then fixed each other to form a first sub-unit. This operation is repeated to obtain five first sub-units. Similarly, five second optical fibers 20K and five spacers 40K are alternately aligned, and then fixed each other to form a second sub-unit. This operation is repeated to obtain five second sub-units. Subsequently, the first and second sub-units are alternately stacked up, and bonded each other to obtain a fiber assembly. After the fiber assembly is disposed in a stainless tube 50K, an epoxy-resin adhesive 51K is supplied into the tube to obtain the optical fiber bundle 4K of this modification, as shown in FIG. 21. In this modification, a distance L between a center of each of the projection ends and a center of an adjacent receiving end is 280 μm.

As a second modification of the fifth embodiment, it is possible to use an optical fiber bundle 4M having first and second optical fibers (10M, 20M) arranged, as shown in FIG. 22. The optical fiber bundle 4M is formed with a plurality of sub-bundles, in each of which a projection end of the first optical fiber 10M is disposed on an end surface of the bundle at a center of a square pattern and four receiving ends of the second optical fibers 20M are disposed at corners of the square pattern. In this modification, diameters of the first and second optical fibers (10M, 20M) are 200 μm and 75 μm, respectively. A distance L between the projection end and an adjacent receiving end is adequately determined to fall within the range of 0.1 mm to 2 mm.

(Sixth Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of a sixth embodiment of the present invention is identical to that of the first embodiment except for the following features. As shown in FIG. 23, an optical fiber bundle 4N is formed with a plurality of sub-bundles, in each of which five projection ends of first optical fibers 10N are disposed on an end surface of the bundle at a center of a square pattern and four corners of the square pattern, and four receiving ends of second optical fibers 20N are disposed on four sides of the square pattern between adjacent projection ends. The sub-bundles are arranged on the end surface of the optical fiber bundle 4N such that one receiving end and two projection ends of each of the sub-bundles are common with an adjacent sub-bundle. A distance L between a projection end and an adjacent receiving end is adequately determined to fall within the range of 0.1 mm to 2 mm.

To make this optical fiber bundle 4N, a plurality of supporting members 40N for supporting the first and second optical fibers (10N, 20N) are used. Each of the supporting members 40N is formed with first grooves 41N having openings at its bottom surface and second grooves 42N having openings at its top surface. The first and second optical fibers (10N, 20N) are respectively disposed in the first and second grooves (41N, 42N) such that projection and receiving ends thereof are alternately aligned.

A method of forming the optical fiber bundle 4N comprises the steps of stacking up the supporting members 40N such that the projection ends of the first optical fibers 10N are disposed adjacent to the receiving ends of the second optical fibers 20N in a stacking direction, as shown in FIG. 24, and bonding the supporting members each other to obtain the optical fiber bundle 4N. This embodiment presents an advantage that a distance between each of the projection ends and an adjacent receiving end can be determined by changing a thickness of the supporting member 40N.

As a first modification of the sixth embodiment, an optical fiber bundle 4P having first and second optical fibers (10P, 20P) arranged, as shown in FIG. 25, can be formed by the following method. That is, a plurality of supporting members 40P for supporting the first and second optical fibers (10P, 20P) are prepared. Each of the supporting members 40P has a coupling portion 41P, a plurality of convex portions 42P, and grooves 43P formed between adjacent convex portions 42P, as shown in FIG. 26. The first and second optical fibers (10P, 20P) are alternately arranged in the grooves 43P of the supporting members 40P. The supporting members 40P mounting thereon the first and second optical fibers (10P, 20P) are stacked up such that projection ends of the first optical fibers are disposed adjacent to receiving ends of the second optical fibers in a stacking direction, as shown in FIG. 27, and then fixed each other to obtain the optical fiber bundle 4P of this modification. In this embodiment, each of the first and second optical fibers (10P, 20P) has a diameter of 200 μm. A thickness T of the coupling portion 41P and a width W

of the convex portions **42P** are 200 μm. Therefore, a distance **L** between a center of each of the projection ends and a center of an adjacent receiving end is 400 μm.

As a second modification of the sixth embodiment, it is possible to use an optical fiber bundle **4Q**, as shown in FIG. 28. The optical fiber bundle **4Q** is formed with receiving ends of second optical fibers **20Q** disposed on an end surface of the bundle at a center and four corners of a square pattern, and projection ends of first optical fibers **10Q** disposed on four sides of the square pattern between adjacent receiving ends. Each of the first and second optical fibers (**10Q**, **20Q**) has a diameter of 500 μm. In addition, the optical fiber bundle **4Q** comprises twelve supplemental second optical fibers **21Q** each having a diameter of 250 μm. Four supplemental second optical fibers **21Q** are arranged around each of the first optical fibers **10Q**, as shown in FIG. 28. A distance **L** between a projection end and a receiving end of the second optical fiber **20Q**, and a distance **L1** between the projection end and an adjacent receiving end of the supplemental second optical fiber **21Q** are adequately determined to fall within the range of 0.1 mm to 2 mm such that the distance **L** is larger than the distance **L1**.

(Seventh Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of a seventh embodiment of the present invention is identical to that of the first embodiment except for a structure of an optical fiber bundle **4R**. That is, as shown in FIG. 29, the optical fiber bundle **4R** is formed with a plurality of first optical fibers **10R** of which projection ends are disposed on an end surface of the bundle along a circular pattern and inside of the circular pattern, and a plurality of second optical fibers **20R** of which receiving ends are disposed along the circular pattern and outside of the circular pattern.

For example, the optical fiber bundle **4R** can be formed by the following method. The first optical fibers **10R** are fixed on a surface of a spacer sheet **40R** by a predetermined interval, and then the second optical fibers **20R** are fixed on the opposite surface of the spacer sheet by the predetermined interval such that each of the receiving ends is positioned just below an adjacent projection end through the spacer sheet, as shown in FIG. 30. The optical fiber bundle **4R** is obtained by making a tube with the spacer sheet **40R** mounting thereon the first and second optical fibers (**10R**, **20R**), as shown in FIG. 29. Alternatively, it is possible to form an optical fiber bundle (not shown) by winding the spacer sheet **40R** in a spiral configuration.

In this embodiment, each of the first and second optical fibers (**10R**, **20R**) has a diameter of 200 μm, and a thickness of the spacer sheet **40R** is 100 μm. Therefore, a distance **L** between each of the projection ends and the adjacent receiving end is 300 μm. Thus, there is an advantage that the distance **L** can be selected by changing a thickness of the spacer sheet **40R**.

As a modification of the seventh embodiment, it is possible to use an optical fiber bundle **4S**, as shown in FIG. 31. That is, the optical fiber bundle **4S** differs from the optical fiber bundle **4R** in that each of receiving ends of second optical fibers **20S** is not positioned just below an adjacent projection end of a first optical fiber **10S** through a spacer tube **40S**. A distance **L** between each of the projection ends and the adjacent receiving end is adequately determined to fall within the range of 0.1 mm to 2 mm.

This optical fiber bundle **4S** can be formed by the following method. Spacer tubes (**40S**, **41S**) having different diameters are prepared. The first optical fibers **10S** are fixed on an outer surface of the spacer tube **41S** along an axial direction of the tube by a predetermined interval. Similarly, the second optical fibers **20S** are fixed on an outer surface of the spacer tube **40S** along an axial direction of the tube by the predetermined interval. Then, the spacer tube **41S** is inserted into the spacer tube **40S** such that the first optical fibers **10S** on the spacer tube **41S** contact an inner surface of the spacer tube **40S**, as shown in FIG. 32, and then fixed to the spacer tube **40S** to obtain the optical fiber bundle **4S**.

(Eight Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of an eighth embodiment of the present invention is identical to that of the first embodiment except that a first optical fiber bundle **4T** and a second optical fiber bundle **70T** are used, as shown in FIG. 33. Therefore, no duplicate explanation to common parts and operation is deemed necessary.

As shown in FIG. 34, the first bundle **4T** is formed with a plurality of sub-bundles, in each of which a projection end of a first optical fiber **10T** is disposed on an end surface of the first bundle at a center of a hexagonal pattern, and six receiving ends of second optical fibers **20T** are disposed at corners of the hexagonal pattern. Each of the first and second optical fibers (**10T**, **20T**) has a diameter of 500 μm. A distance **L** between each of the projection ends and an adjacent receiving end is determined to fall within the range of 0.1 mm to 2 mm such that the receiving end can selectively sense the resulting radiation emitted from a dermis layer **91T** of a skin **9T** of the subject.

On the other hand, the second bundle **70T** is formed with a plurality of sub-bundles, in each of which a projection end of a third optical fiber **71T** is disposed on an end surface of the second bundle at a center of a hexagonal pattern, and six receiving ends of fourth optical fibers **72T** are disposed at corners of the hexagonal pattern. The third optical fibers **71T** are connected at

the opposite ends to a light source unit, and the fourth optical fibers **72T** are connected at the opposite ends to a light receiving unit **5T**, as shown in FIG. 33. Each of the third and fourth optical fibers (**71T**, **72T**) has a diameter of 250 μm. In the second bundle **70T**, a distance **L1** between each of the projection ends and an adjacent receiving end is determined such that the receiving end can selectively sense the resulting radiation emitted from an epidermis layer **90T** of the skin **9T**.

By using a subtraction between adsorption spectra obtained through the first and second bundles (**4T**, **70T**). It is possible to provide an adsorption spectrum of only the dermis layer **91T**.

(Ninth Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of a ninth embodiment of the present invention is identical to that of the first embodiment except that a plurality of luminescent semiconductor diodes **10U** are used in place of the first optical fibers **10**, and receiving elements **20U** are used in place of the second optical fibers **20**. Each of the diodes **10U** and the receiving elements **20U** is of a square shape of 100 μm x 100 μm. Five diodes **10U** are aligned by a pitch **P** of 200 μm to obtain a diode array. Five receiving elements **20U** are aligned by the pitch P of 200 μm to obtain a receiving element array. As shown in FIG. 35, the diode array is separated from the receiving element array by a distance L of 100 μm.

(Tenth Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of a tenth embodiment of the present invention is identical to that of the first embodiment except that receiving elements **20V** are used in place of the second optical fibers **20**. As shown in FIG. 36, an optical fiber bundle **4V** is formed with five sub-bundles, each of which is composed of four receiving elements **20V** disposed on an end surface of the bundle at corners of a square pattern and a projection end of a first optical fiber **10V** disposed on the end surface at a center of the square pattern. A distance **L** between a center of the projection end and a center of an adjacent receiving element **20V** is determined to fall within the range of 0.1 mm to 2 mm.

(Eleventh Embodiment)

A device for non-invasive determination of a glucose concentration in the blood of a subject of an eleventh embodiment of the present invention is explained below. That is, as shown in FIG. 37, a light source unit comprises a halogen lamp **1X** of about 150 W having a reflection mirror **2X**, and a first lens system **3X** disposed between the halogen lamp and a first optical fiber **10X**. An optical fiber bundle **4X** is formed with the first optical fiber **10X** having a diameter of 750 μm for projecting near-infrared radiation on a skin **9X** of the subject and a second optical fiber **20X** having a diameter of 750 μm for receiving a resulting radiation emitted from the inside of the skin. A projection end of the first optical fiber **10X** and a receiving end of the second optical fiber **20X** are exposed at an end surface of the bundle **4X**, as shown in FIG. 38. A distance **L** between the projection end and the receiving end is determined to fall within the range of 0.1 mm to 2 mm.

The resulting radiation received by the second optical fiber **20X** is introduced through a slit **60X** into a flat-field type diffraction grating unit **5X** as a spectroscope of the resulting radiation, and then sent to an array-type light receiving unit **6X** of 256 photo-diodes made of In-Ga-As and having a wavelength-sensitivity of 0.9 μm to 2.1 μm, which is cooled by the use of Peltier elements (not shown). In FIG. 37, numeral **7X** designates an A/D converter disposed between the light receiving unit **6X** and a spectrum analyzing unit **8X** comprising a microcomputer.

In the spectrum analyzing unit **8X**, a spectrum analysis of the resulting radiation provided by the second optical fiber **20X** is made, and then a multivariate analysis is performed by the use of an adsorption spectrum of near-infrared radiation of 1.4 μm to 1.8 μm to determine the glucose concentration in the blood of the subject.

As a modification, it would be possible to use an optical fiber bundle of any one of the above explained embodiments in place of the bundle **4X** of the eleventh embodiment.

LIST OF REFERENCE NUMERALS

1	halogen lamp
2	diffraction grating unit
3	stepping motor unit
4	optical fiber bundle
5	light receiving unit
6	spectrum analyzing unit
9	skin
10	first optical fiber
20	second optical fiber
20a	second optical fiber
20b	second optical fiber
91	dermis layer
4A	optical fiber bundle
10A	first optical fiber
20A	second optical fiber
4B	optical fiber bundle
10B	first optical fiber
20B	second optical fiber
40B	circular plate
41B	through hole
4C	optical fiber bundle
10C	first optical fiber
20C	second optical fiber
4D	optical fiber bundle

10D first optical fiber
20D second optical fiber
4E optical fiber bundle
5E light receiving unit
10E first optical fiber
20E second optical fiber
30E third optical fiber
4F optical fiber bundle
5F light receiving unit
10F first optical fiber
20F second optical fiber
21F second optical fiber
30F third optical fiber
90F epidermis layer
91F dermis layer
4G optical fiber bundle
10G first optical fiber
20G second optical fiber
21G second optical fiber
4H optical fiber bundle
10H first optical fiber
20H second optical fiber
30H third optical fiber
4J optical fiber bundle
10J first optical fiber
20J second optical fiber
40J supporting member
41J coupling portion
42J convex portion
43J groove
4K optical fiber bundle
10K first optical fiber
20K second optical fiber
40K spacer
50K stainless tube
51K epoxy-resin adhesive
4M optical fiber bundle
10M first optical fiber
20M second optical fiber
4N optical fiber bundle
10N first optical fiber
20N second optical fiber
40N supporting member
41N first groove
42N second groove
4P optical fiber bundle
10P first optical fiber
20P second optical fiber
40P supporting member
41P coupling portion
42P convex portion
43P groove
4Q optical fiber bundle
10Q first optical fiber
20Q second optical fiber
21Q second optical fiber
4R optical fiber bundle
10R first optical fiber
20R second optical fiber
40R spacer sheet
4S optical fiber bundle
10S first optical fiber
20S second optical fiber
40S spacer tube
41S spacer tube
4T first bundle
5T light receiving unit
9T skin
10T first optical fiber
20T second optical fiber
70T second bundle
71T third optical fiber
72T fourth optical fiber
90T epidermis layer
91T dermis layer
10U luminescent semiconductor diode
20U receiving element
4V optical fiber bundle
10V first optical fiber
20V receiving element
1X halogen lamp
2X reflection mirror
3X first lens system
4X optical fiber bundle
5X flat-field type diffraction grating unit
6X array-type light receiving unit
7X A/D converter
8X spectrum analyzing unit
9X skin
10X first optical fiber
20X second optical fiber
60X slit
1Y light source
2Y first lens system
3Y second lens system
9Y skin
10Y input radiation conductor
20Y sensing radiation conductor
30Y spectrum analyzer/detector
40Y data processor
50Y display monitor
60Y output recorder
1Z primary light
2Z resulting secondary light
3Z resulting secondary light
9Z skin
10Z projection site
20Z first detection site
30Z second detection site

Claims

1. A device for the non-invasive determination of glucose concentration in the blood of a subject, comprising:

a light source (1) for producing near-infrared radiation having successive wavelengths within the range of 1300 to 2500 nm,

light projecting means (10) for projecting said near-infrared radiation on the skin (9) of the subject,

light receiving means (20) for receiving resulting radiation emitted from inside the skin, and

means (6) for analysing the spectrum of the resulting radiation to determine the glucose concentration in the blood,

characterised in that

said light receiving means (20) is separated from said light projecting means (10) by a distance (L) within the range of 0.1 to 2 mm to selectively sense the resulting radiation emitted from a dermis layer (91) positioned under the epidermis layer of the skin (9), and

said spectrum analysing means (6) determines said glucose concentration in the blood according to the spectrum analysis and a statistically obtained correlation between the glucose concentration in the dermis layer and that in the blood.

2. The device of claim 1, wherein said near-infrared radiation comprises successive wavelengths from 1400 to 1800 nm and/or from 2000 to 2500 nm.

3. The device of claim 1, wherein said light projecting means includes a plurality of first optical fibres (10) each of which is connected at its one end to said light source and provides said near-infrared irradiation from its opposite, projecting end, and wherein said light receiving means includes a plurality of second optical fibres (20) each of which is connected at its one end to said spectrum analysing means (6) and receives the resulting radiation at its opposite, receiving end.

4. The device of claim 3, wherein said first optical fibres (10) form a bundle (4) in cooperation with said second optical fibres (20), the projecting ends of said first optical fibres and the receiving ends of said second optical fibres being exposed at an end surface of said bundle in such a pattern that the centre of each projecting end is separated from that of an adjacent receiving end by said distance (L).

5. The device of claim 4, wherein said bundle (4, 4A, 4B, 4C, 4D, 4E) includes a plurality of sub-bundles, in each of which the projecting end of a first optical fibre (10, 10A, 10B, 10C, 10D, 10E) is disposed in the end surface of said bundle at the centre of a hexagonal pattern and the receiving ends of six second optical fibres (20, 20A, 20B, 20C, 20D, 20E) are disposed at the corners of said hexagonal pattern.

6. The device as set forth. in claim 5, wherein adjacent sub-bundles have at least one of said receiving ends in common.

7. The device of claim 5, further comprising supplemental light receiving means including a plurality of third optical fibres (30E), wherein each of said third optical fibres is connected at its one end to said spectrum analysing means and selectively receives at its opposite, receiving end the resulting radiation emitted from said epidermis layer, and the receiving end of each third optical fibre being disposed in the end surface of said bundle (4E) between said projecting end and one of said receiving ends in said hexagonal pattern.

8. The device of claim 4, wherein said bundle (4J, 4K) includes a plurality of sub-bundles, in each of which the projecting end of a first optical fibre (10J, 10K) is disposed in the end surface of said bundle at a centre of a rectangular pattern and the receiving ends of four second optical fibres (20J, 20K) are disposed at the corners of said rectangular pattern.

9. The device of claim 4, wherein said bundle (4N, 4P) includes a plurality of sub-bundles, in each of which the projecting ends of five first optical fibres (10N, 10P) are disposed in the end surface of said bundle at the centre and the four corners of a square pattern and the receiving ends of four second optical fibres (20N, 20P) are disposed on the four sides of said square pattern between adjacent projecting ends.

10. The device of claim 9, wherein adjacent sub-bundles have one receiving end and two projecting ends in common.

11. The device of claim 4, wherein the projecting ends of said first optical fibres (10R, 10S) are disposed in the end surface of said bundle along a circular pattern and inside thereof and the receiving ends of said second optical fibres (20R, 20S) are disposed along said circular pattern and outside thereof.

12. The device of claim 4, wherein said second optical fibres (20F, 21F, 20G, 21G) have at least two different diameters.

13. The device of claim 12, wherein said bundle (4F, 4G) includes a plurality of sub-bundles, in each of which the projecting end of a first optical fibre (10F, 10G) and the receiving ends of two second optical fibres (20F, 21F, 20G, 21G) having different diameters are disposed in the end surface of said bundle in a circular pattern.

14. The device of claim 13, further comprising a sup-

plemental light receiving means which includes a plurality of third optical fibres (30F), wherein each of said third optical fibres is connected at its one end to said spectrum analysing means and selectively receives at its opposite, receiving end the resulting radiation emitted from said epidermis layer (90F), the receiving end of each third optical fibre being disposed in the end surface of said bundle closer to the projecting end of said first optical fibre (10F) than the receiving ends of said second optical fibres (20F, 21F) in said circular pattern.

15. The device of claim 3, wherein each of said first and second optical fibres (10, 20) have diameters between 70 and 1000 μm.

16. The device of claim 4, further comprising a spacer (40J, 40N, 40P, 40R, 40S) for providing an interval between each projecting end and the adjacent receiving end.

17. The device of claim 3, wherein the number of said first optical fibres (10) is half the number of said second optical fibres (20).

18. The device of claim 3, further comprising a supplemental light receiving means including a plurality of third optical fibres (30E, 30F), wherein each of said third optical fibres is connected at its one end to said spectrum analysing means and selectively receives at its opposite, receiving end the resulting radiation emitted from said epidermis layer.

19. The device of claim 4, wherein the centre of each of said projecting ends is at least separated from the centre of the adjacent receiving end by a distance L expressed by the equation

$$L = \{\sqrt{2} \times (d1 + d2)\}/2,$$

wherein d1 is the diameter of said first optical fibre (10) and d2 is the diameter of said second optical fibre (20).

20. The device as set forth, in claim 4, wherein said distance (L) is with the range of 0.2 to 1 mm.

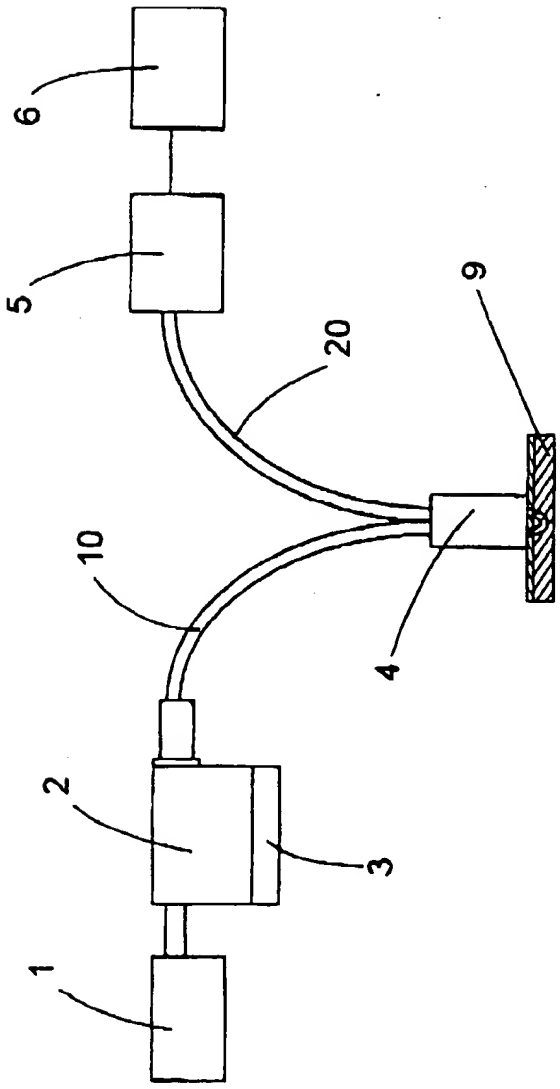

FIG. 1

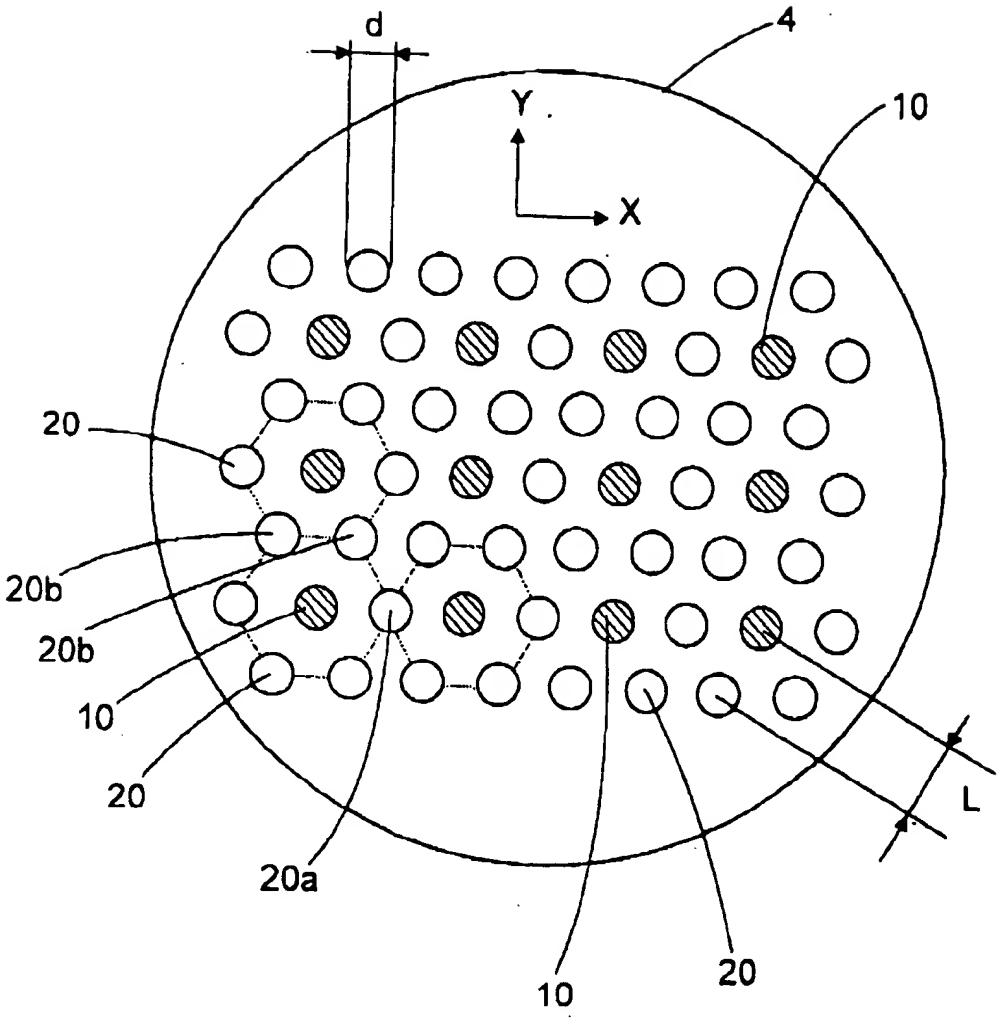

FIG. 2

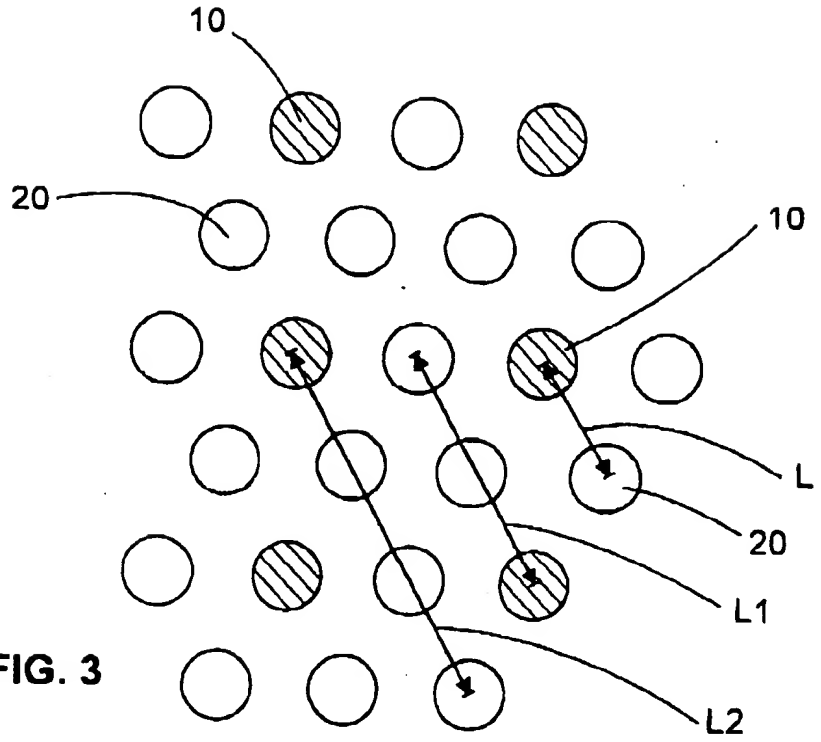

FIG. 3

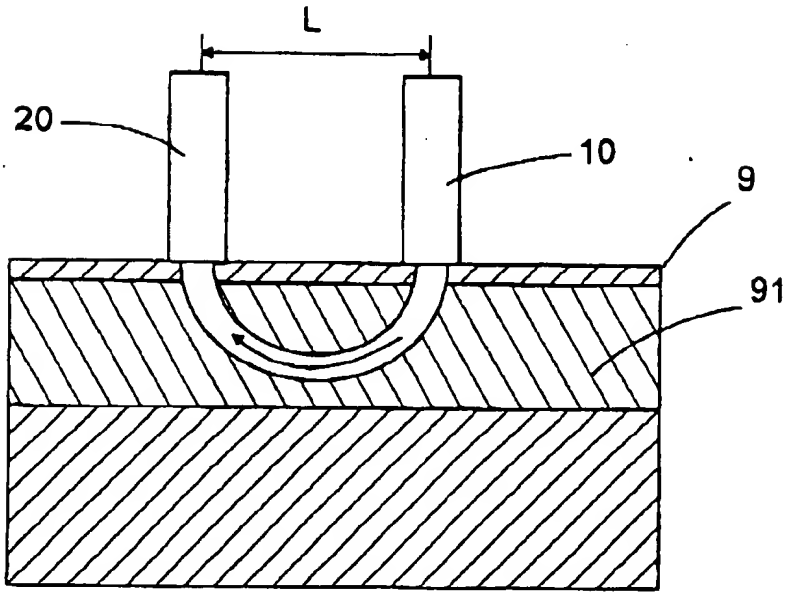

FIG. 4

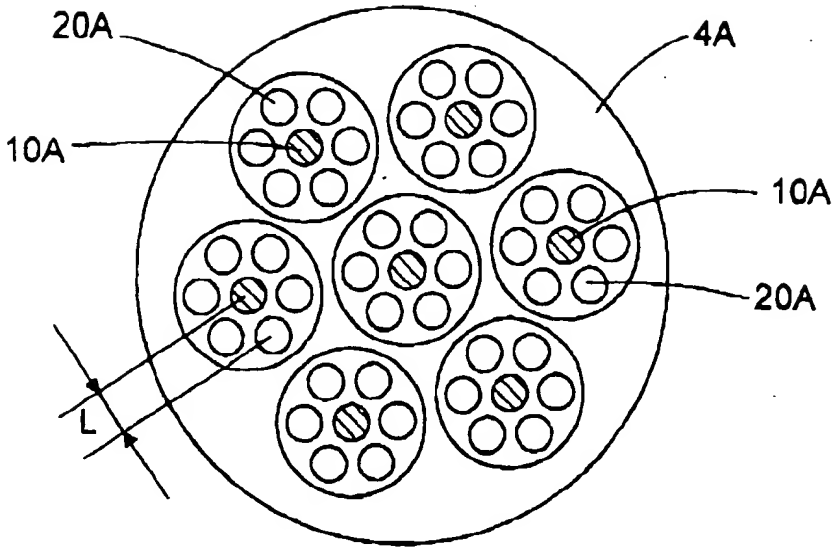

FIG. 5

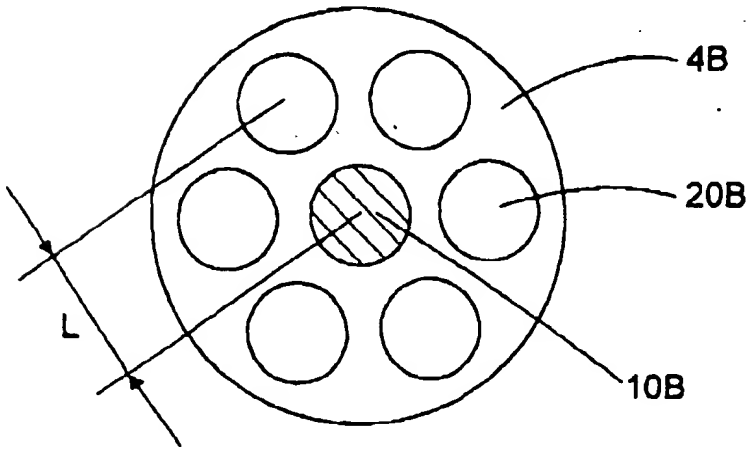

FIG. 6A

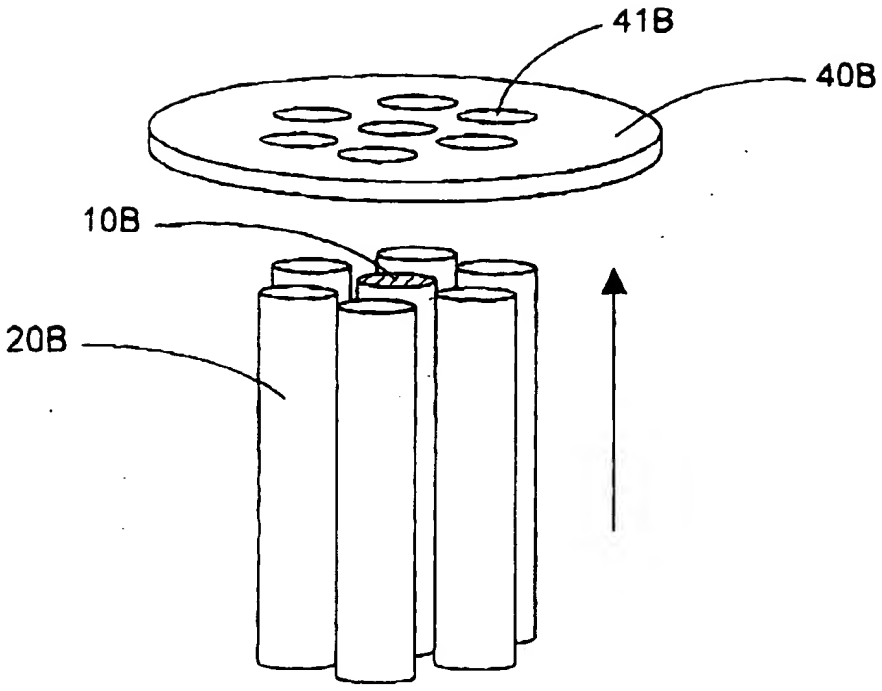

FIG. 6B

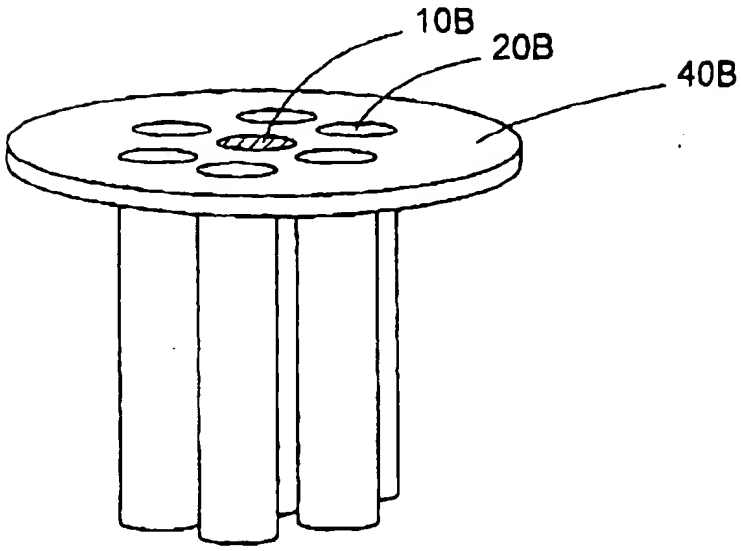

FIG. 6C

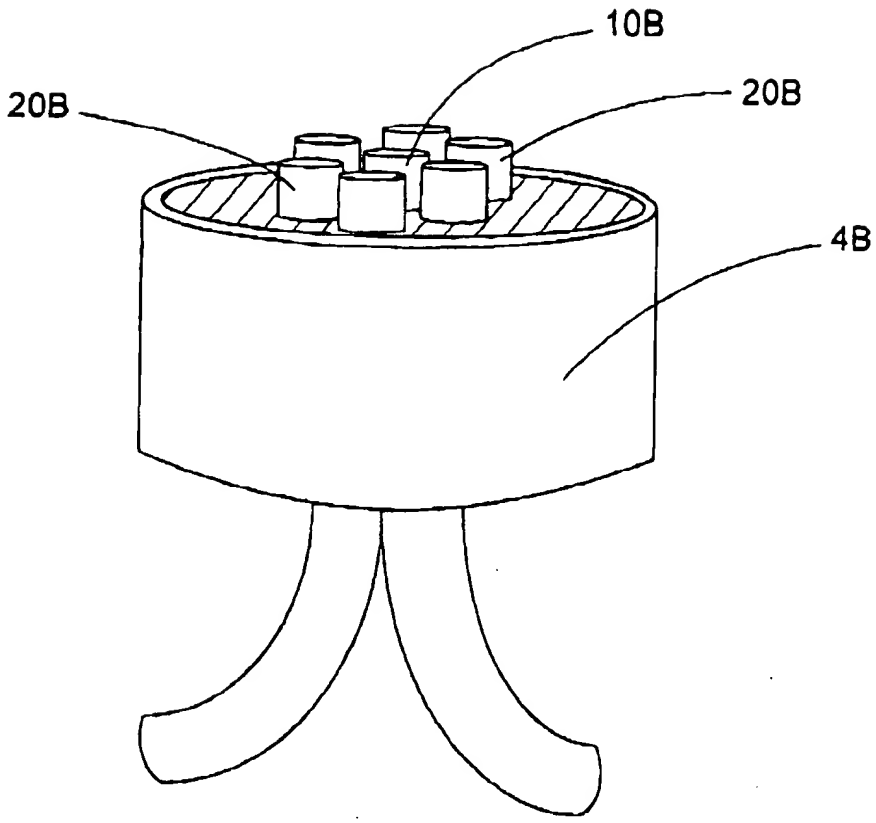

FIG. 7

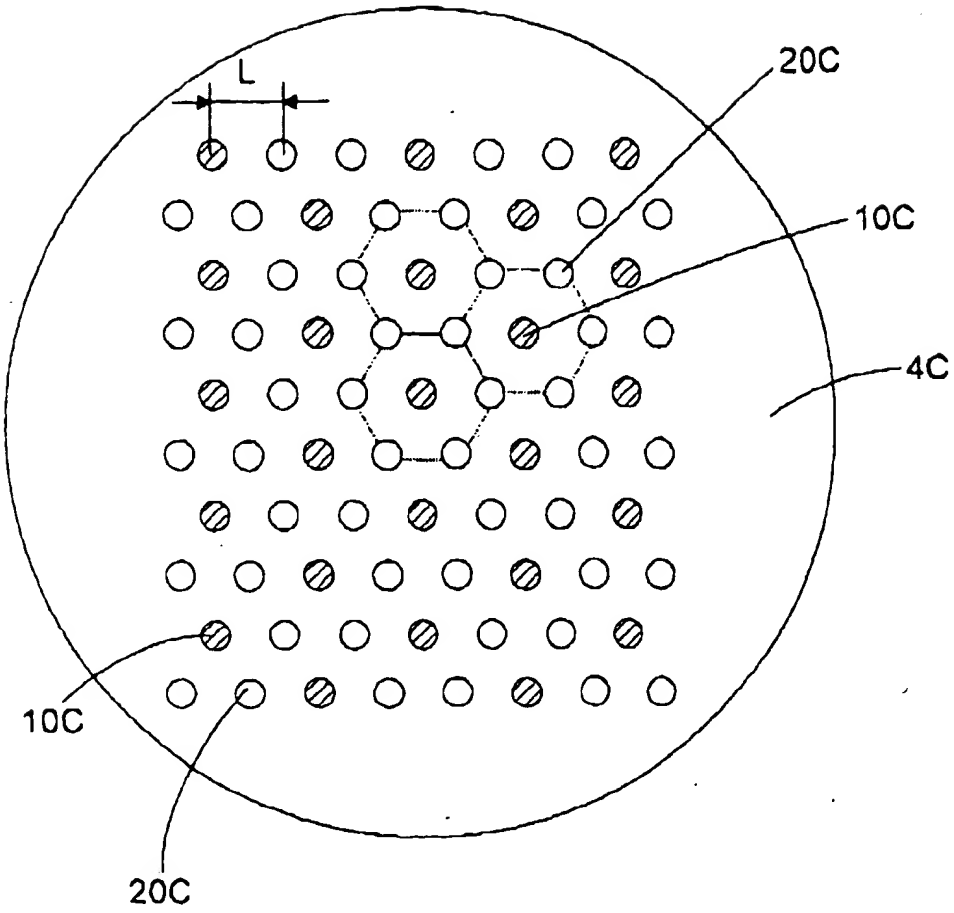

FIG. 8

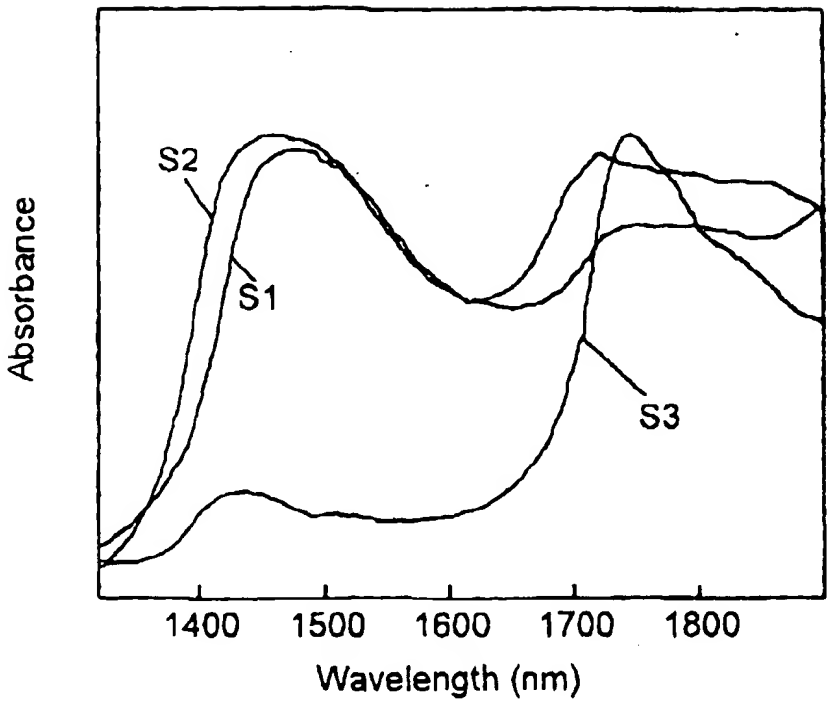

FIG. 9

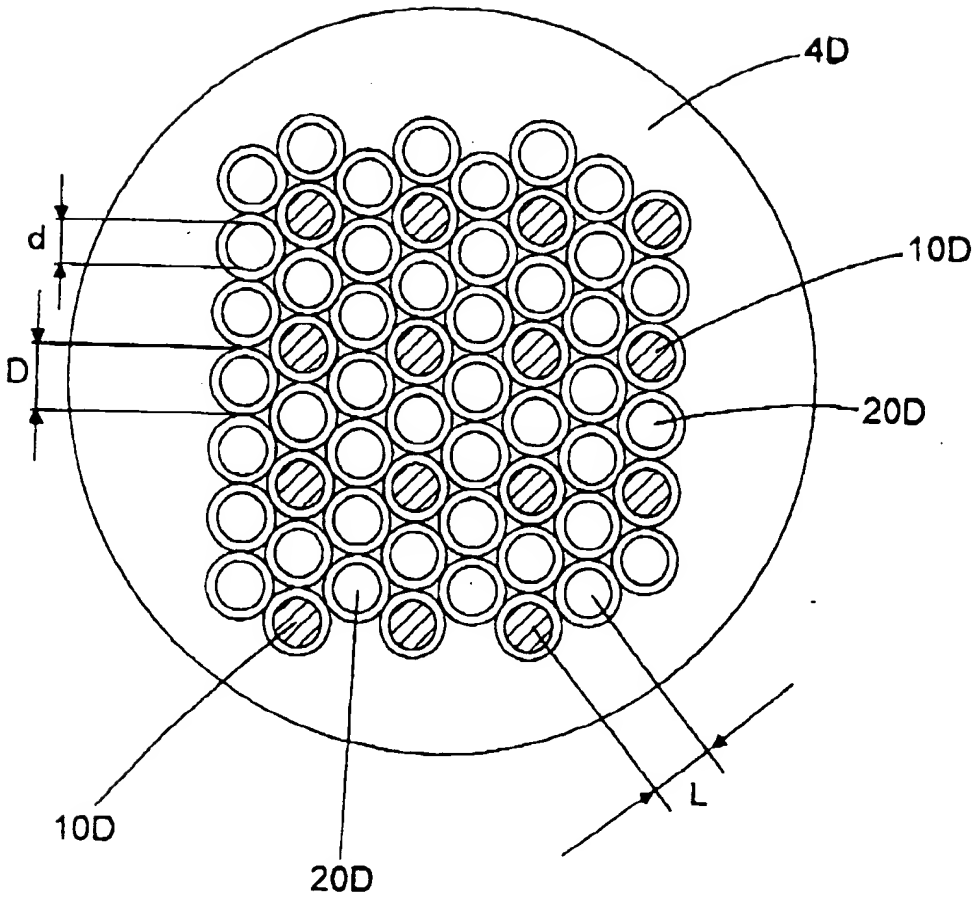

FIG. 10

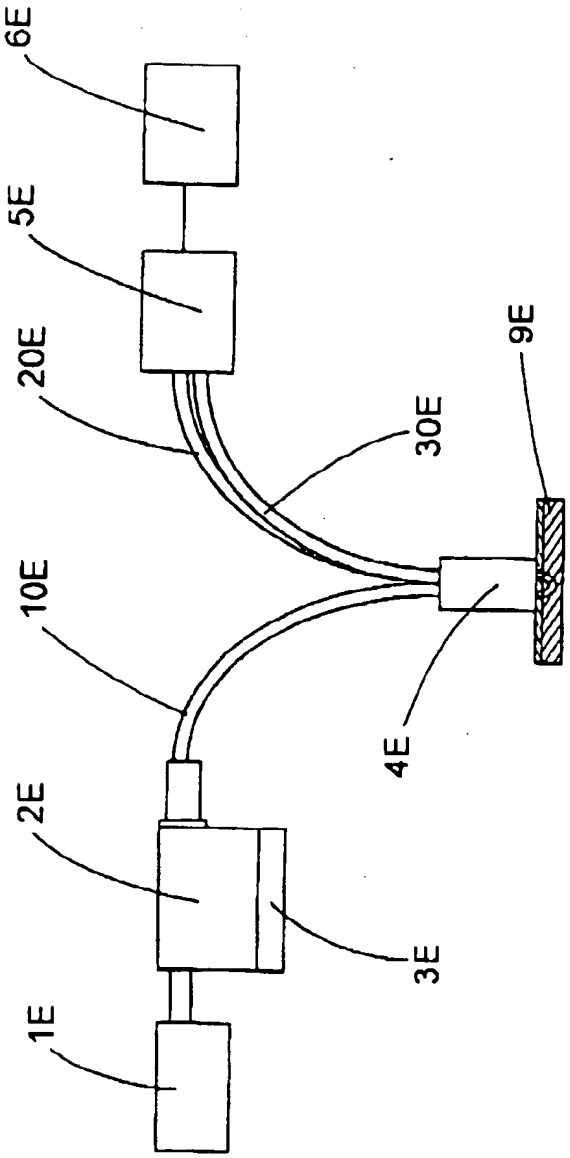

FIG. 11

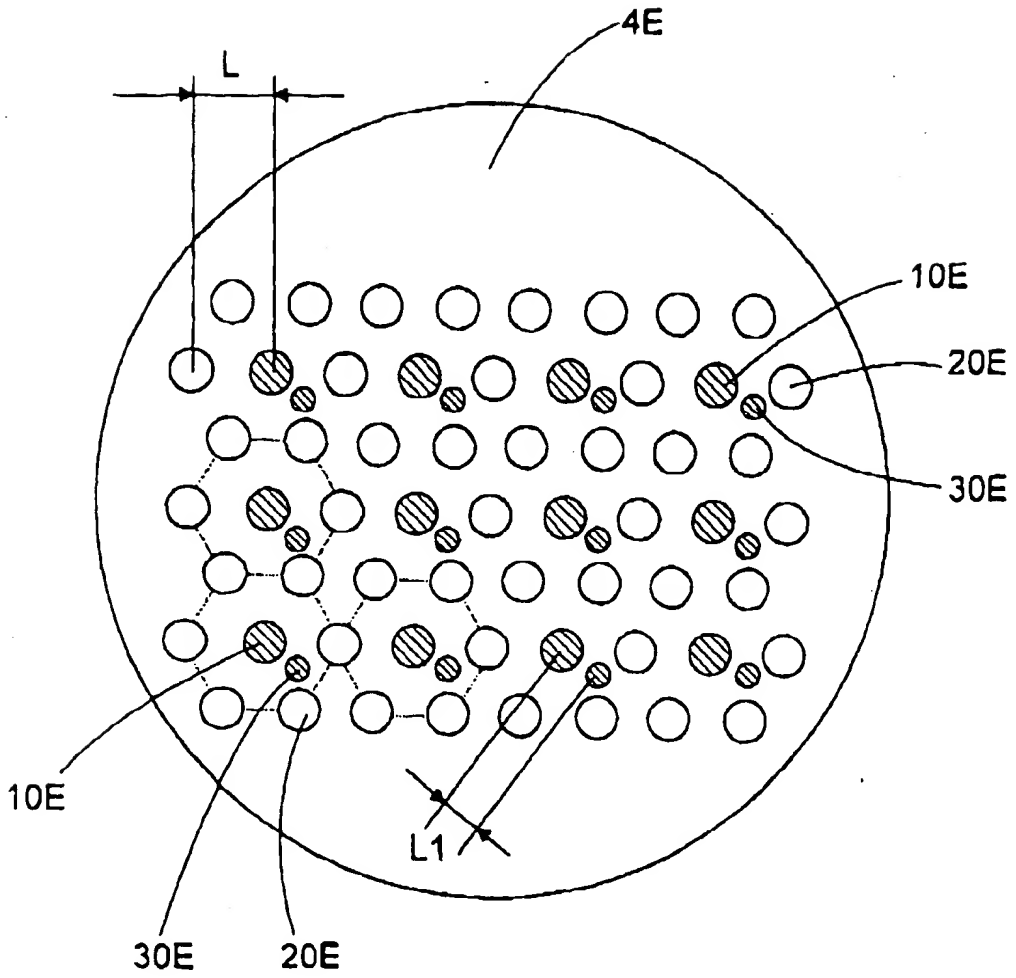

FIG. 12

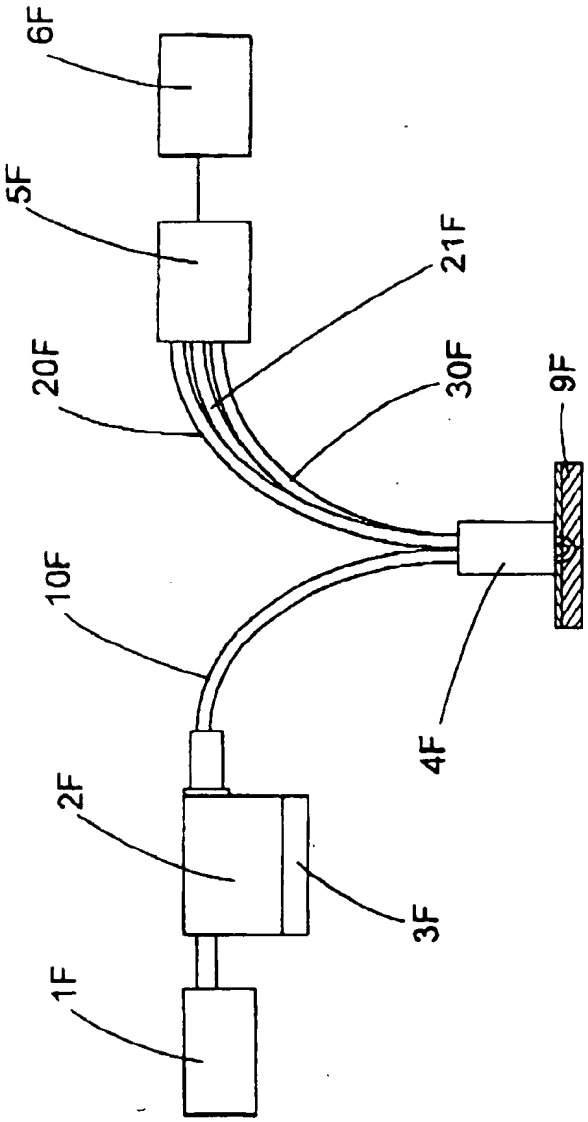

FIG. 13

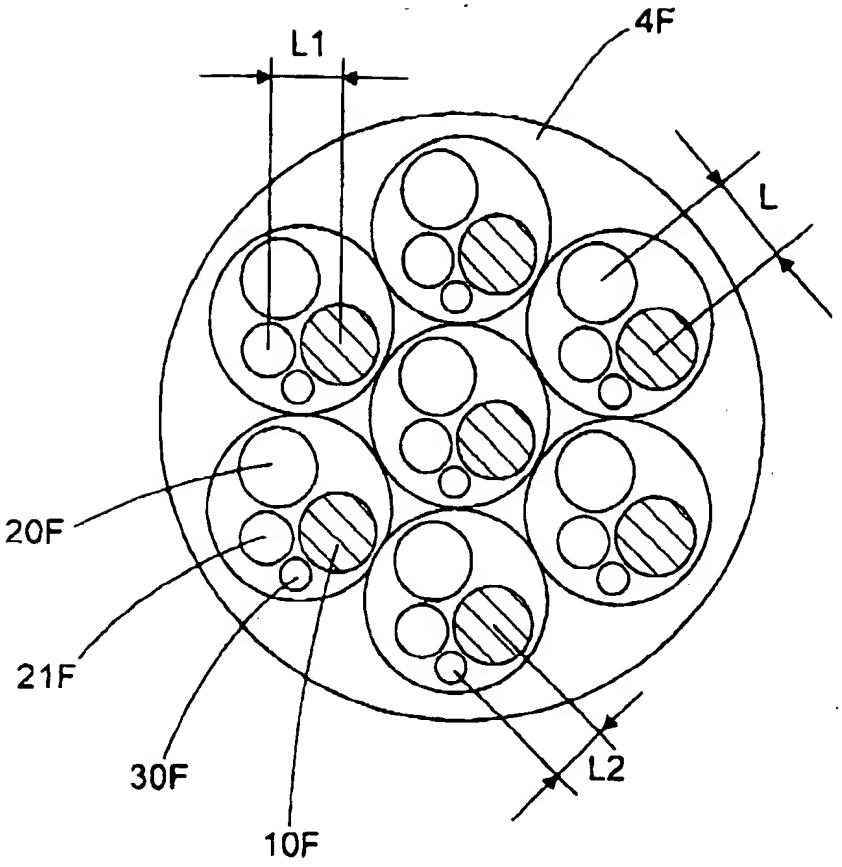

FIG. 14

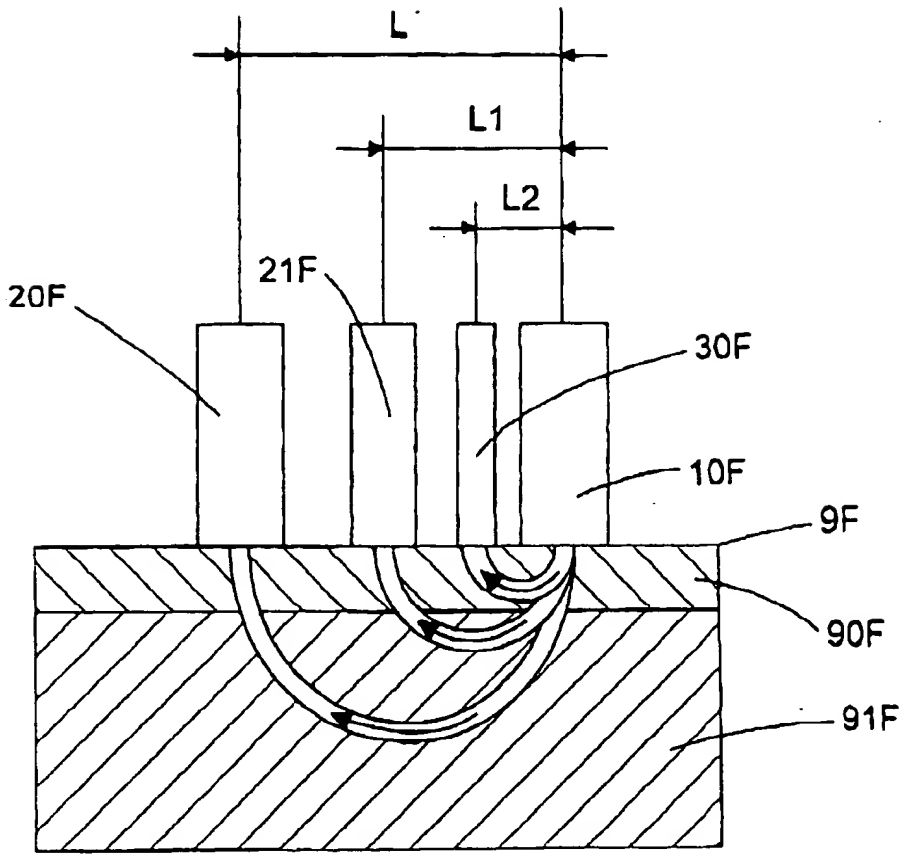

FIG. 15

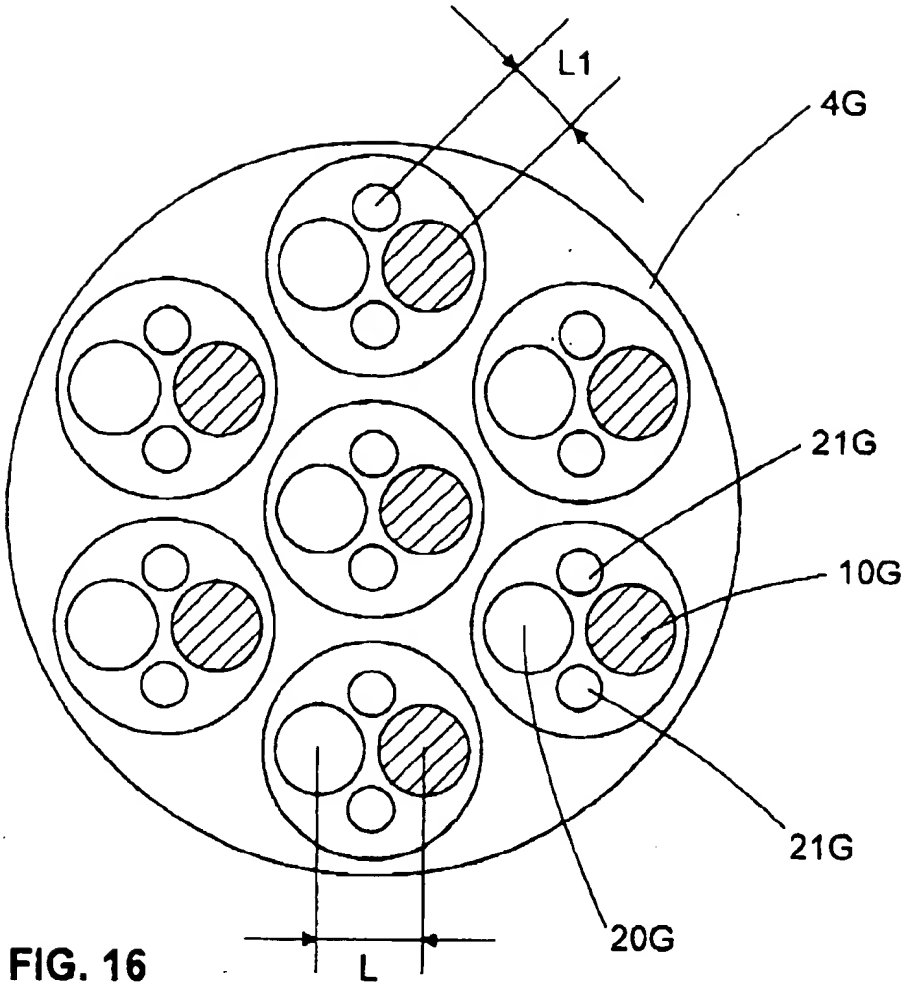

FIG. 16

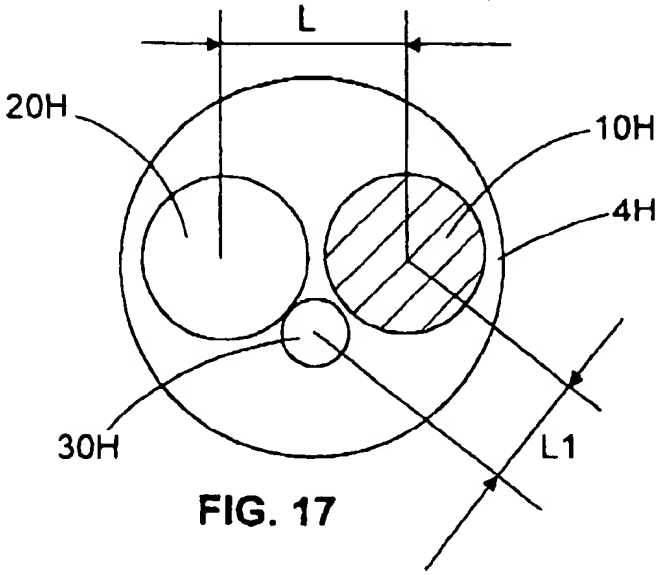

FIG. 17

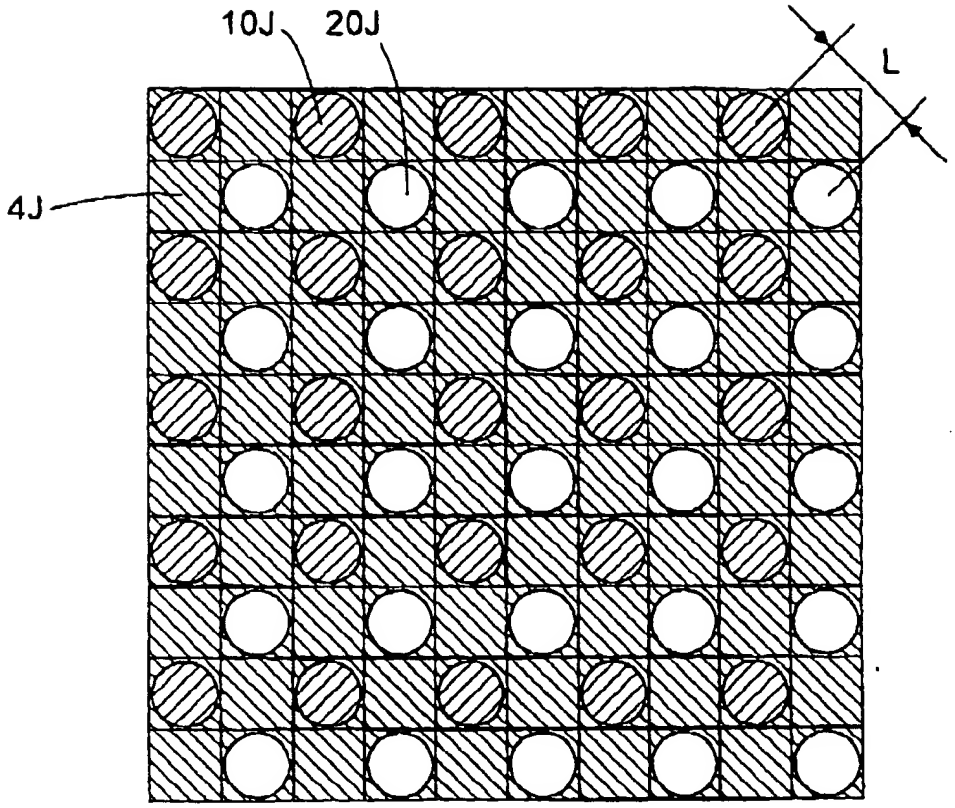

FIG. 18

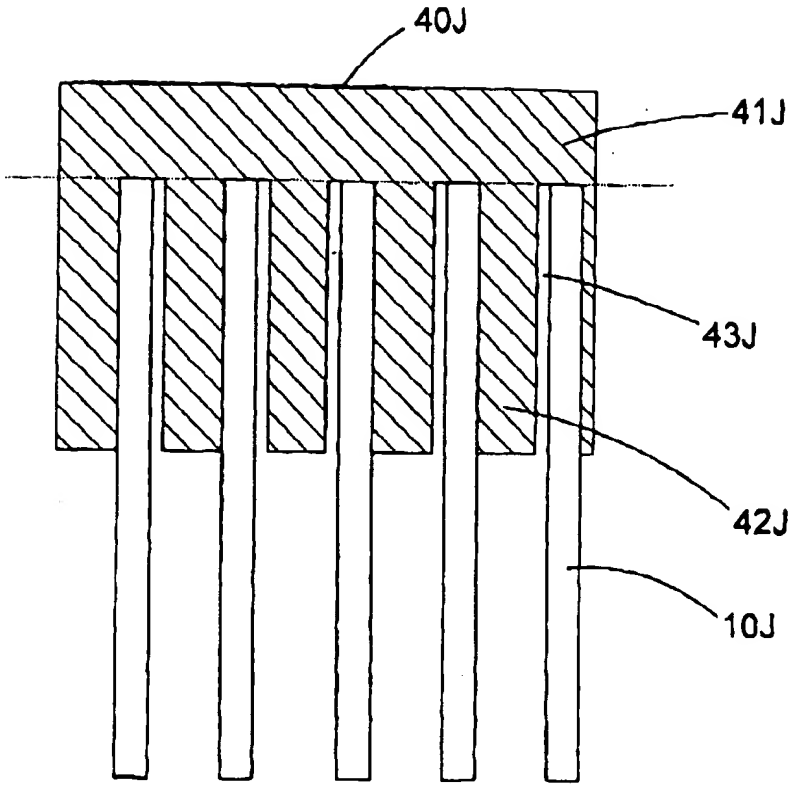

FIG. 19

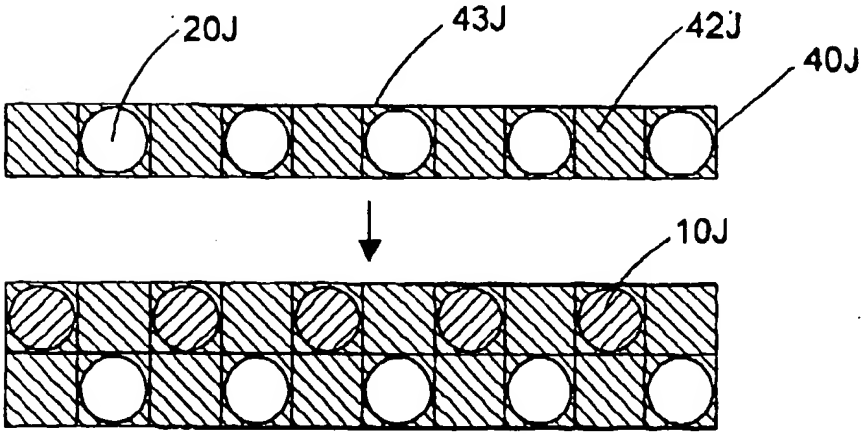

FIG. 20

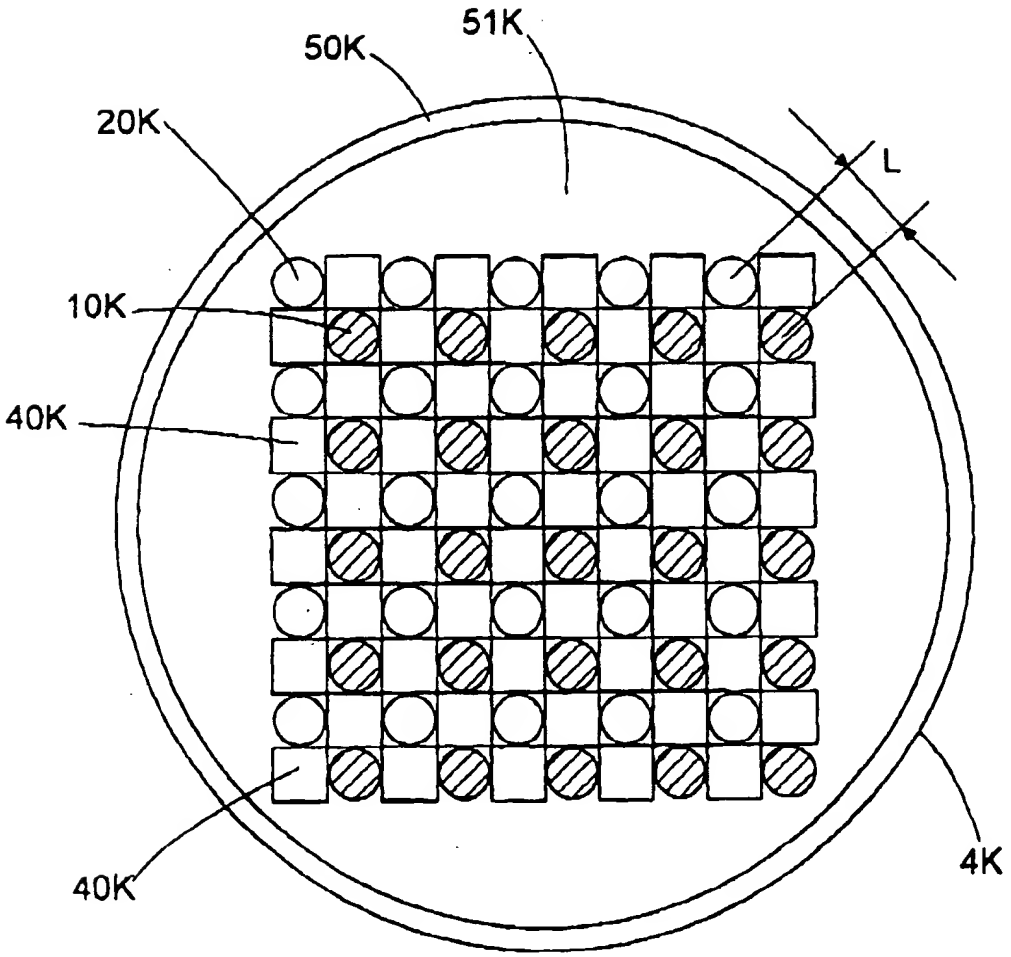

FIG. 21

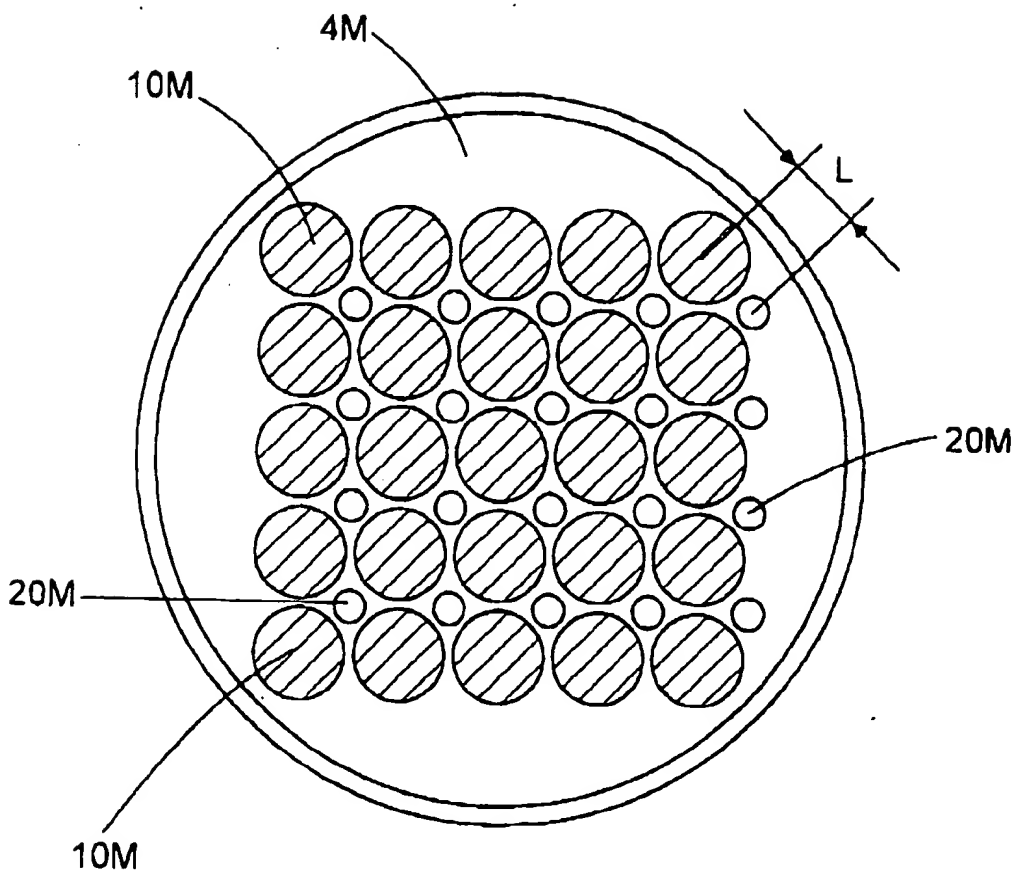

FIG. 22

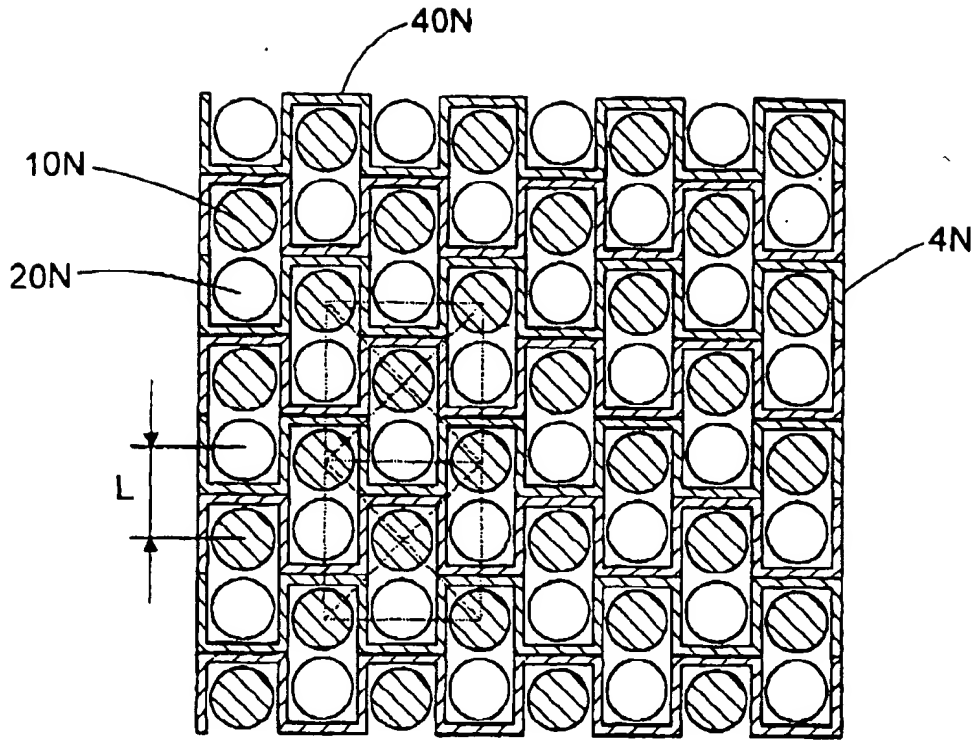

FIG. 23

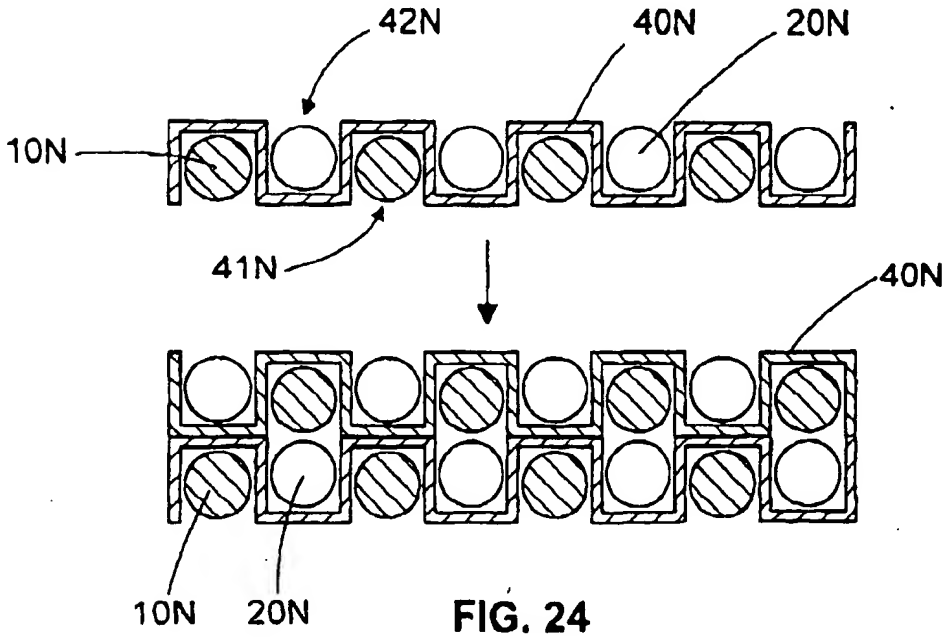

FIG. 24

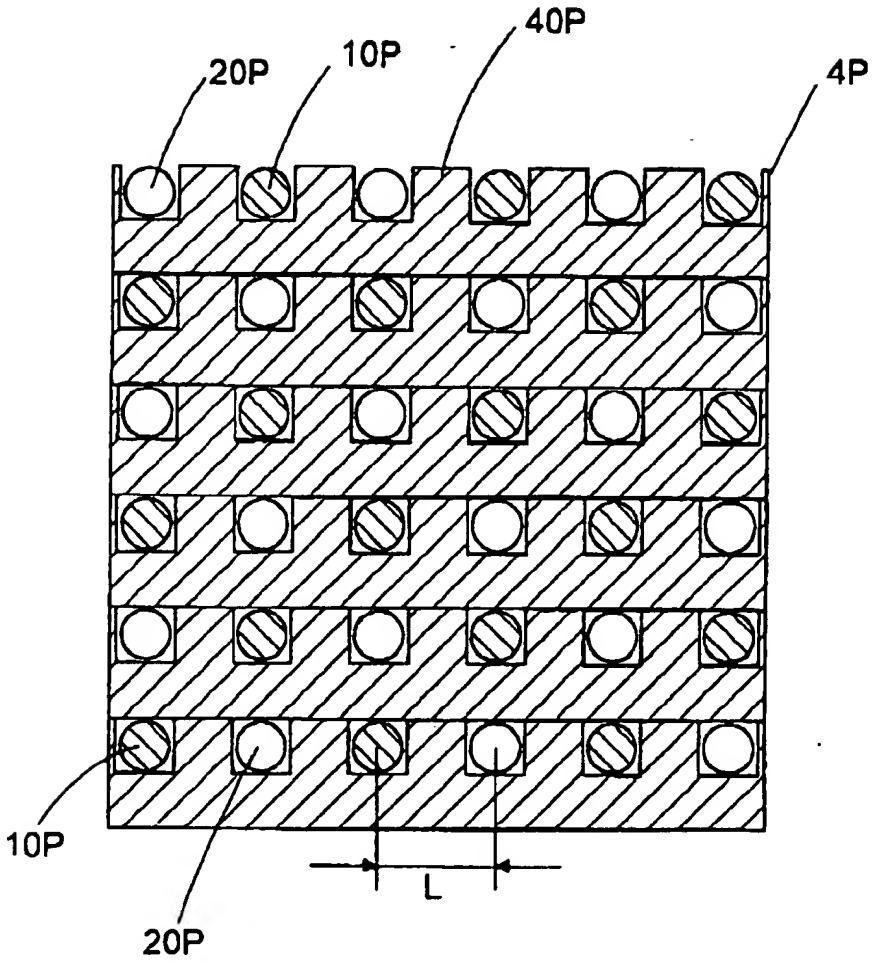

FIG. 25

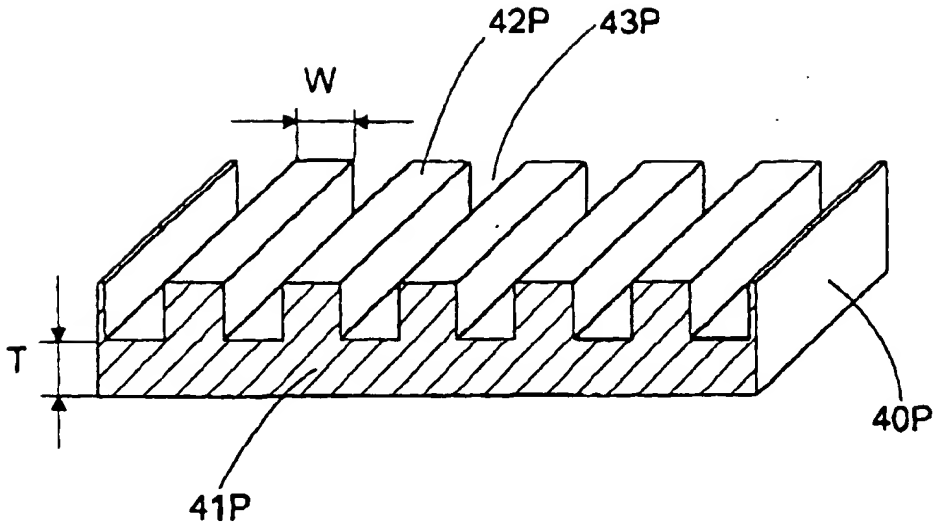

FIG. 26

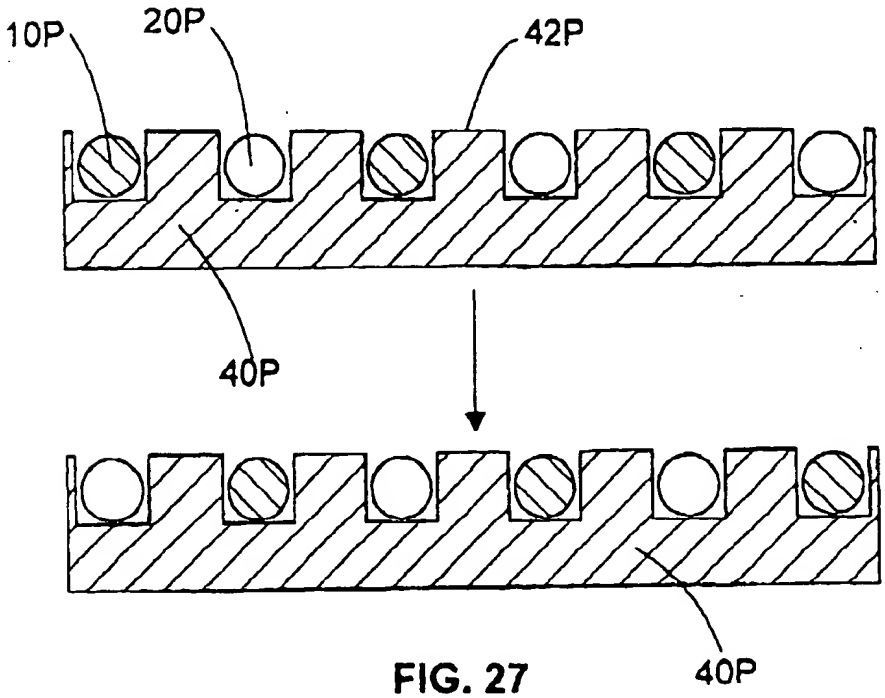

FIG. 27

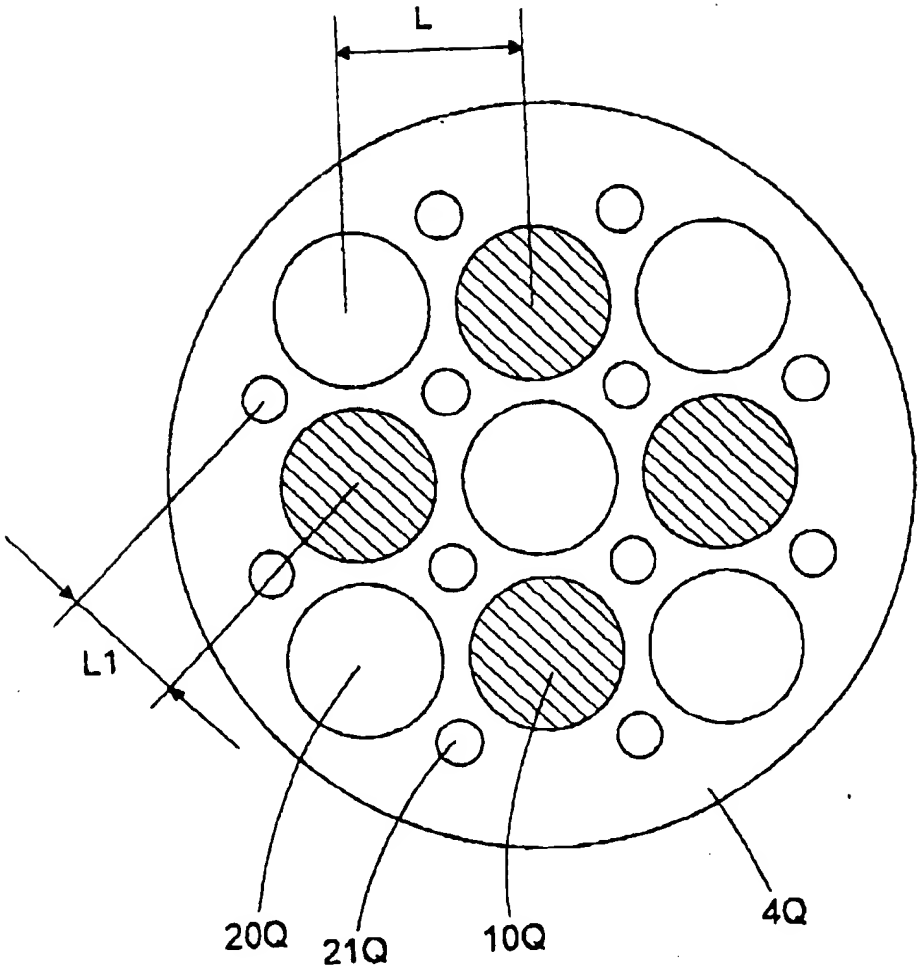

FIG. 28

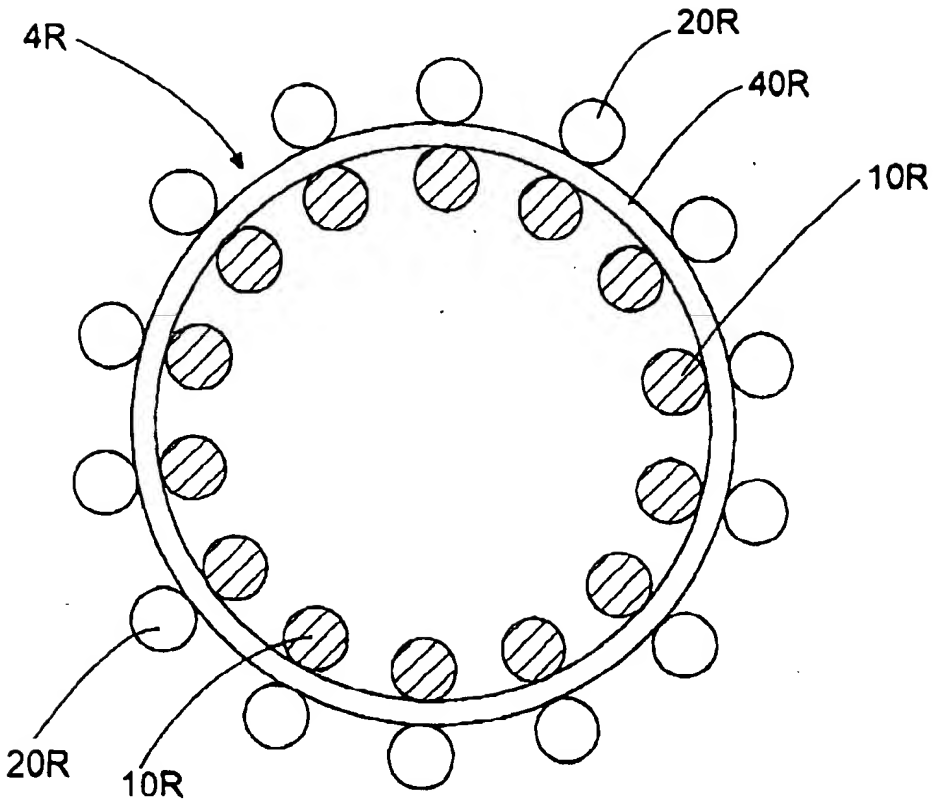

FIG. 29

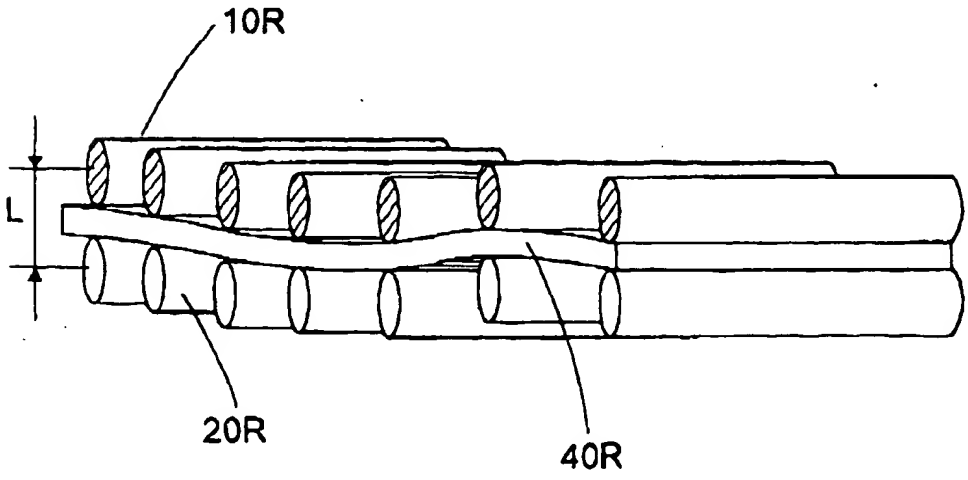

FIG. 30

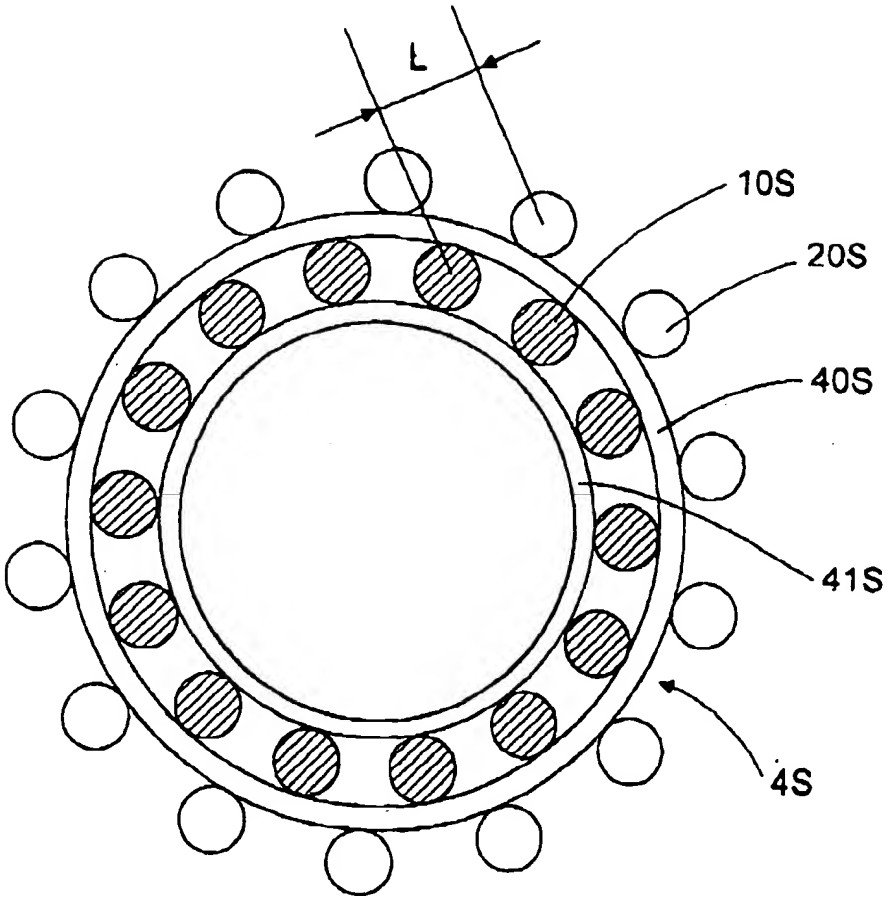

FIG. 31

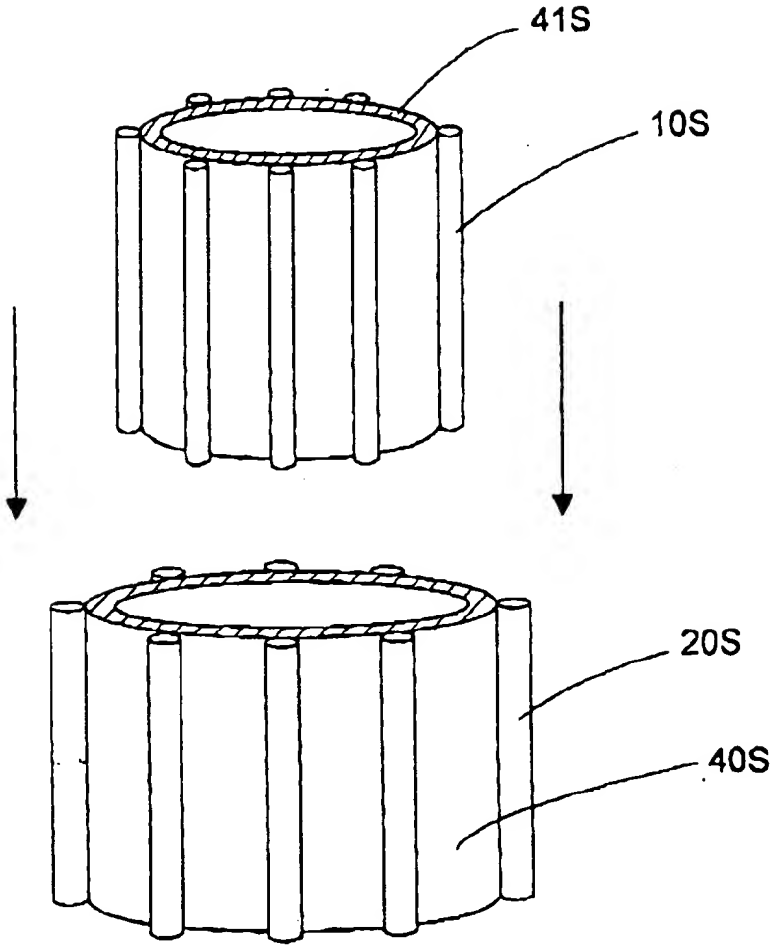

FIG. 32

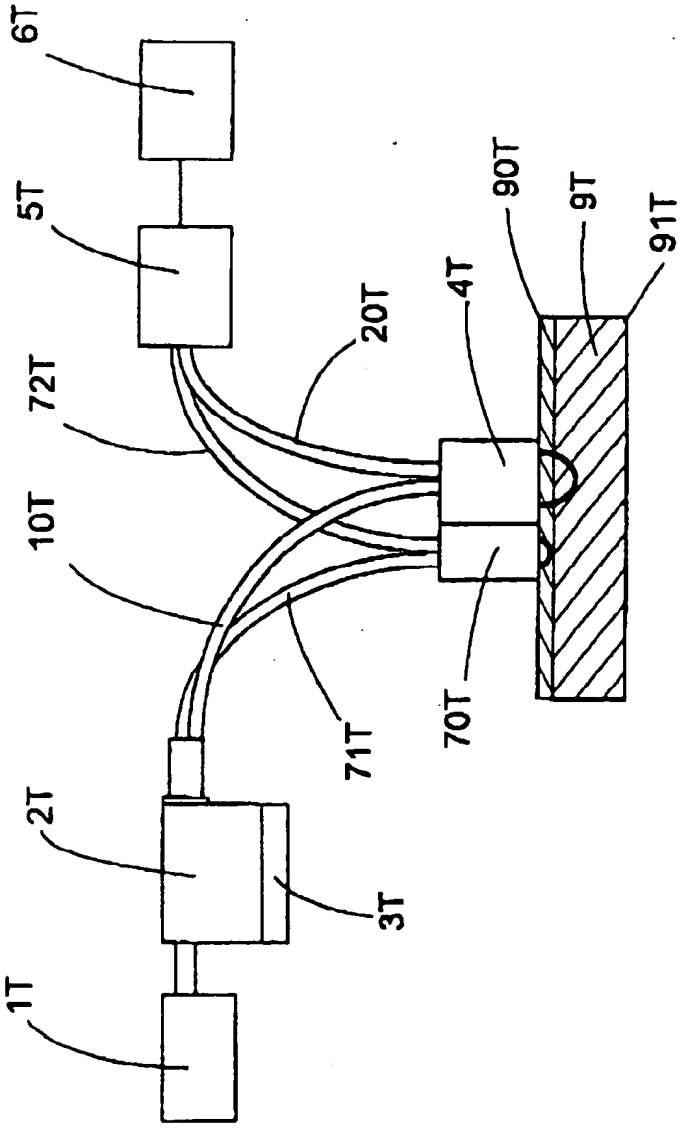

FIG. 33

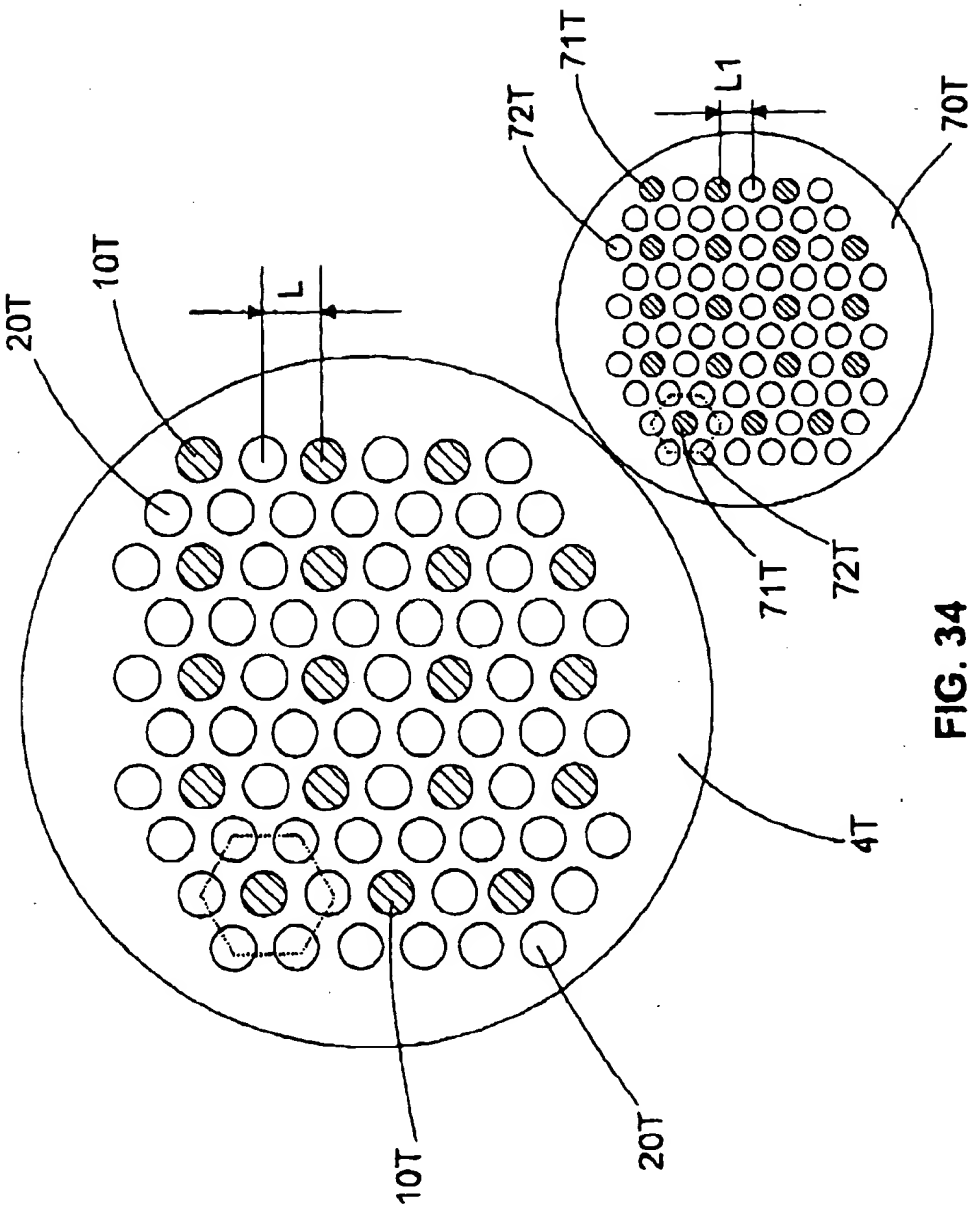

FIG. 34

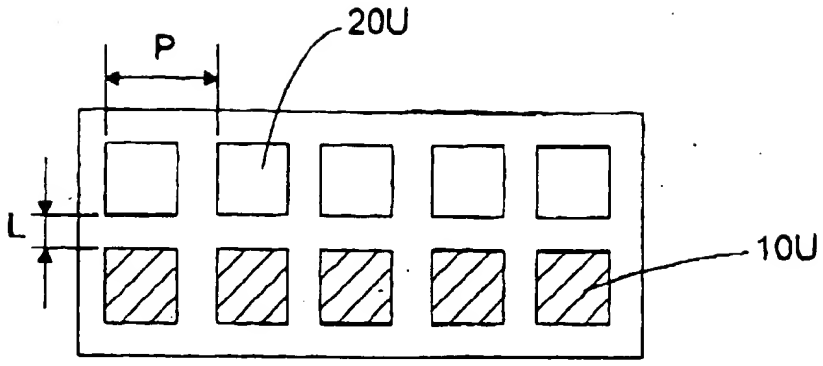

FIG. 35

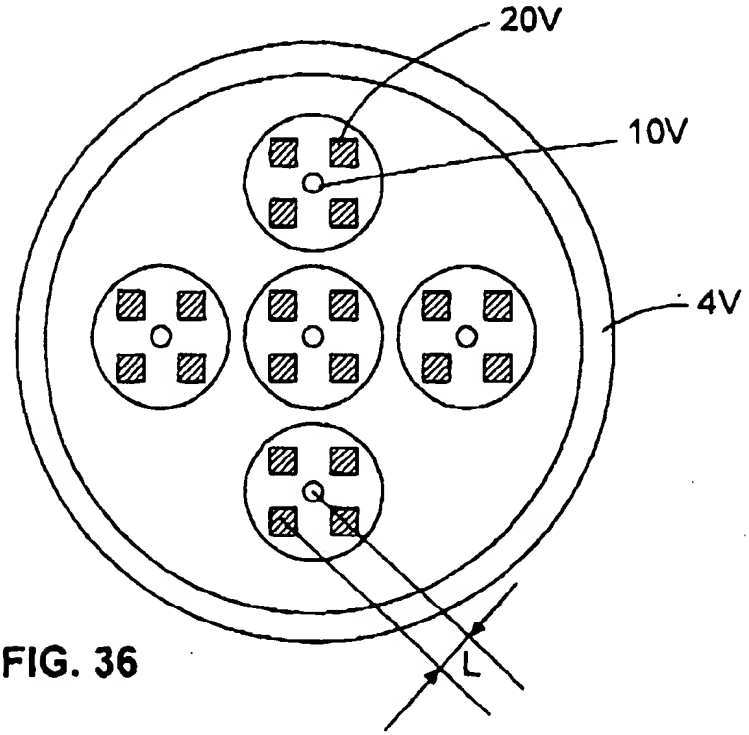

FIG. 36

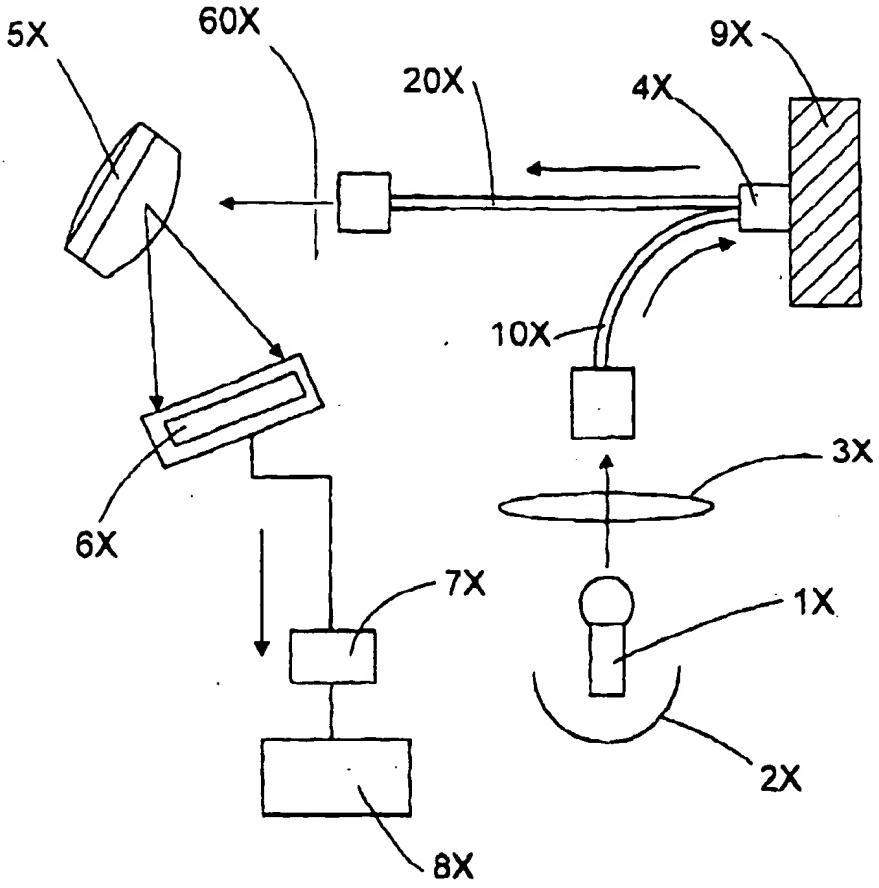

FIG. 37

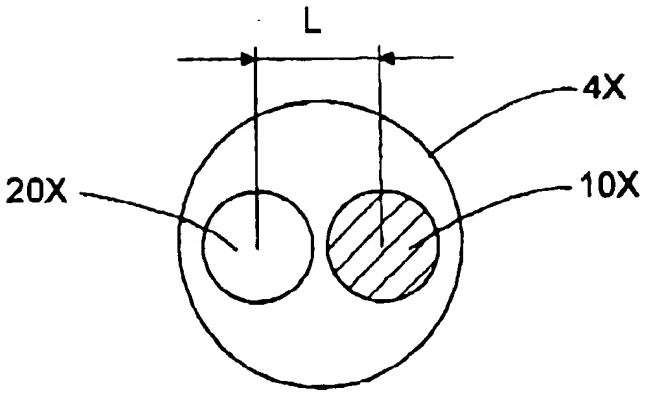

FIG. 38

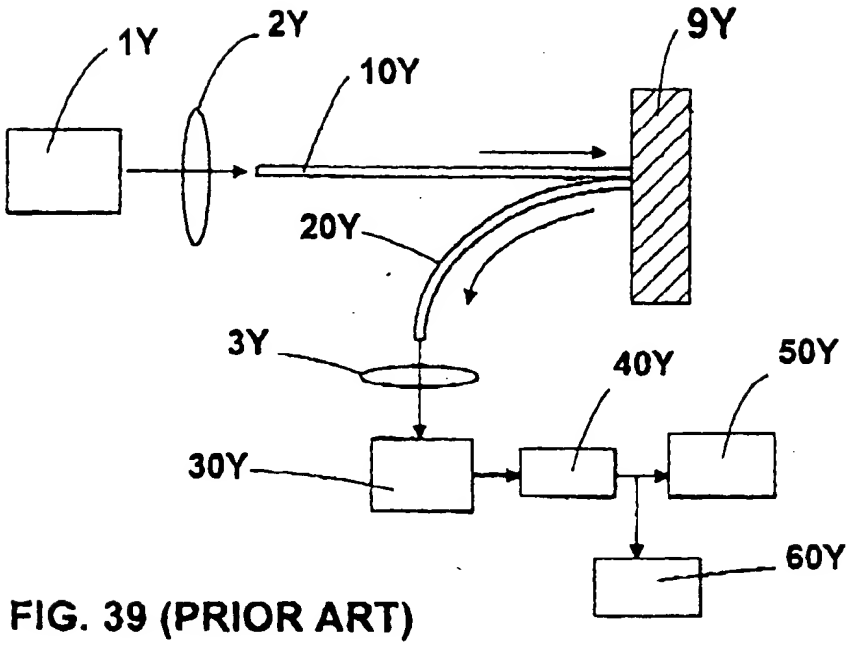

FIG. 39 (PRIOR ART)

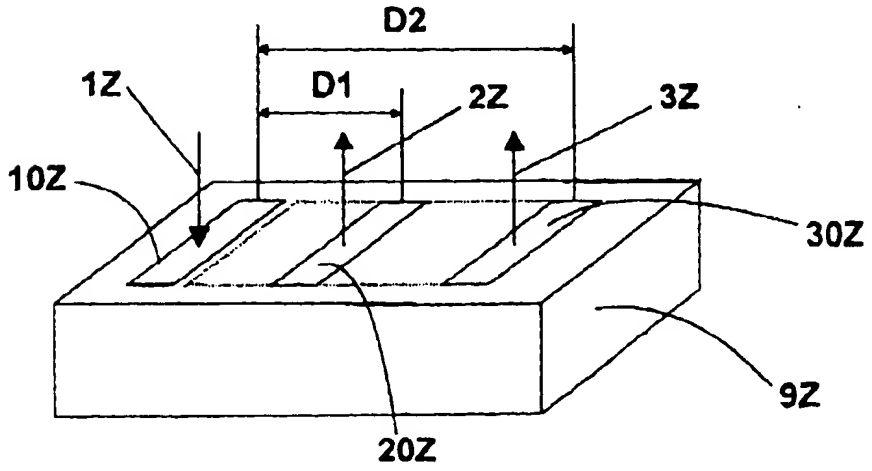

FIG. 40 (PRIOR ART)